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The Relation of Calcium and Phosphorus Intake and Digestion and the Effects of Vitamin D Feeding on the Utilization of Calcium and Phosphorus by Lactating Dairy Cows

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INTRODUCTION

Eleven experiments involving 170 5- to 7-day digestion balance trials were conducted primarily to determine the effects of vitamin D feeding on the utilization of calcium and phosphorus by lactating dairy cows. During these experiments, conducted between November 1958 and November 1967, different amounts of vitamin D_2, ranging from 20,000 I.U./day to 640,000 I.U./day, were fed. Several different concentrates and forages also were fed during this 9-year period using rations that were similar to those fed on many dairy farms, which resulted in a rather wide range of calcium and phosphorus intakes. It was possible, therefore, in addition to vitamin D_2 effects, to study the relation of both calcium and phosphorus intake and digestion on the utilization of calcium and phosphorus.

EXPERIMENTAL METHODS AND PROCEDURES

The supplemental vitamin D_2 source used in these experiments was Fleischman's irradiated dry yeast, type 142-F (Standard Brands, Inc., 625 Madison Ave., New York, N. Y., and Clinton Corn Processing Co., Clinton, Iowa [Division of Standard Brands Inc.]), containing 142,000 I.U./gram or 64 million I.U./lb. When grain concentrate was fed, the irradiated yeast was mixed with the concentrate. When no grain was fed, the irradiated yeast was administered orally in gelatin capsules using a baling gun.

Digestion balance trials were conducted using a technique previously described (6) in which the cows were maintained in stanchion stalls similar to those they usually occupied (Fig. 1), thus avoiding the long periods of adjustment required when elevated digestion crates were used. All cows were well adjusted to the rations fed prior to the digestion trials, except in experiment 9 where a Latin square design with a 7-day adjustment period was used. Parameters measured are indicated in Tables 1A-11. Serum calcium was determined by the method of Clark and Collip (5) and phosphorus by the modified calorimetric method of Briggs (4). Feed, milk, urine, and feces samples were analyzed using adaptations of the same methods after wet ashing with five parts nitric acid and one part perchloric acid and adjusting to pH 4.0-4.5 (7).

The following are formulae for some of the calculations that were made:

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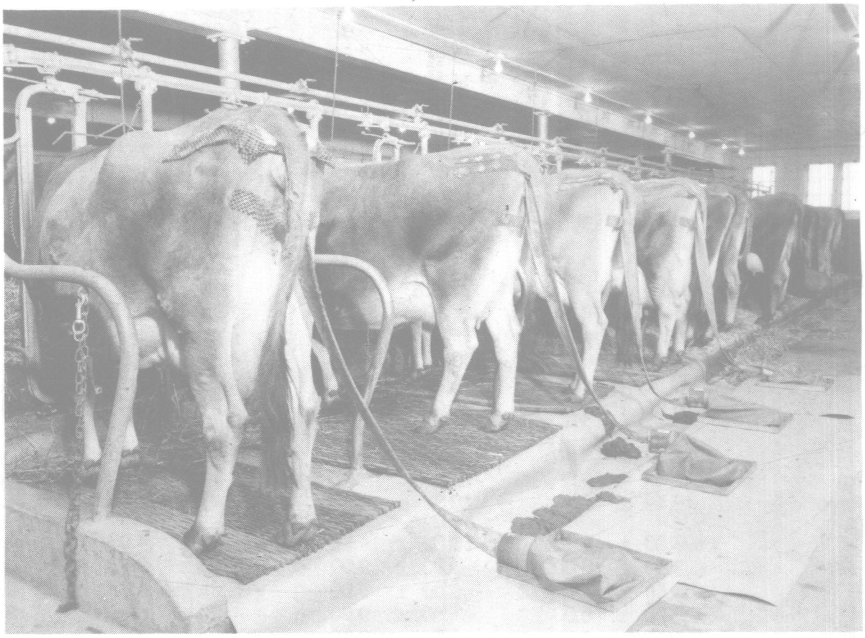

FIG. 1.—Collection of urine and feces for digestion balance trials was carried out in the stanchion stalls regularly occupied by the cows (6).

Digested (g/d) = Intake − Amount Excreted in Feces
Digested % = (Digested ÷ Intake) × 100
Balance = Intake − Outgo (Milk + Feces + Urine)
Used (g/d) = Amount in Milk + Balance
Used % = (Amount in Milk + Balance) ÷ Intake × 100

Based on the observation of Holemans and Meyer (9) that, in humans, a close relation existed between fecal phosphorus and fecal calcium divided by the Ca:P ratio in the diet, calculations were made (Tables 1A-11) for the following: fecal Ca/feed Ca:P ratio, fecal Ca/feed P:Ca ratio, fecal P/feed Ca:P ratio, and fecal P/feed P:Ca ratio. Phosphorus digested/feed P:Ca ratio was also calculated and is shown in Tables 1A-11.

Each experiment is described separately and the group means of the various parameters measured plus standard errors are presented in tabular form. Significant differences among the group means were determined by least squares analysis of variance and ranked using

TABLE 1A.—Effects of Vitamin D_2 and Grain Feeding on Ca and P Utilization by Cows Fed First Cutting Alfalfa-Brome Grass Soilage.

	No Grain No Vitamin D_2	Grain Fed No Vitamin D_2	No Grain + Vitamin D_2	Grain Fed + Vitamin D_2
No. of Cows (Trials)	6	2	2	2
Body Wt. (kg)	388.00 ± 5.81	434.00 ± 4.50	370.00 ± 0.00	416.00 ± 2.00
Milk (kg/d)	10.85 ± 0.82^{B}‡	14.55 ± 2.45^{AB}	11.85 ± 1.85^{AB}	15.40 ± 0.60^{A}
Dry Matter Intake (kg/d)	9.80 ± 0.31^{C}	11.90 ± 0.30^{B}	10.20 ± 1.10^{BC}	14.10 ± 0.00^{A}
Feed Ca (%)	0.58 ± 0.06	0.53 ± 0.14	0.56 ± 0.15	0.55 ± 0.09
Feed P (%)	0.36 ± 0.02	0 38 ± 0.00	0.37 ± 0.06	0.42 ± 0.04
Feed Ca:P Ratio	1.67 ± 0.21	1.40 ± 0.30	1.50 ± 0.20	1.35 ± 0.35
Feed P:Ca Ratio	0.67 ± 0.11	0.78 ± 0.20	0.69 ± 0.08	0.80 ± 0.21
Feces Ca (g/d)	44.00 ± 6.14	40.00 ± 14.00	48.50 ± 19.20	52.50 ± 21.50
Urine Ca (g/d)	3.33 ± 0.52	3.50 ± 1.30	4.30 ± 0.40	4.05 ± 1.65
Milk Ca (g/d)	19.00 ± 1.44^{B}	27.50 ± 3.50^{A}	21.50 ± 3.50^{AB}	25.00 ± 4.00^{AB}
Ca Outgo (g/d)	66.33 ± 7.41	71.00 ± 19.00	74.50 ± 23.50	81.50 ± 27.50
Ca Intake (g/d)	57.33 ± 6.23	62.50 ± 17.50	58.50 ± 21.50	72.00 ± 19.00
Ca Balance (g/d)	−9.00 ± 2.77	−8.50 ± 1.50	−16.00 ± 2.00	−9.50 ± 8.50
Ca Digested (g/d)	13.33 ± 2.44	22.50 ± 3.50	10.00 ± 2.00	19.50 ± 2.50
Ca Digested (%)	24.12 ± 3.76	37.35 ± 4.85	18.30 ± 3.30	30.10 ± 11.40
Ca Used (g/d)	10.00 ± 2.52	19.00 ± 2.00	5.50 ± 1.50	15.50 ± 4.50
Ca Used (%)	18.47 ± 4.06	32.05 ± 5.75	9.80 ± 1.00	24.90 ± 12.80
Feces P (g/d)	25.33 ± 1.33	28.00 ± 4.00	29.50 ± 3.50	31.50 ± 1.50
Urine P (g/d)	0.17 ± 0.01^{B}	0.22 ± 0.02^{AB}	0.20 ± 0.06^{AB}	0.26 ± 0.01^{A}
Milk P (g/d)	10.67 ± 0.80^{B}	16.50 ± 2.50^{A}	10.50 ± 1.50^{B}	12.50 ± 0.50^{AB}
P Outgo (g/d)	36.00 ± 1.86	44.50 ± 6.50	40.00 ± 5.00	44.00 ± 1.00
P Intake (g/d)	36.00 ± 2.22^{B}	43.00 ± 3.00^{AB}	38.50 ± 10.50^{AB}	50.50 ± 1.50^{A}
P Balance (g/d)	0.00 ± 2.91	−1.50 ± 3.50	−1.50 ± 5.50	6.50 ± 2.50
P Digested (g/d)	10.67 ± 2.33	15.00 ± 1.00	9.00 ± 7.00	19.00 ± 3.00
P Digested (%)	28.43 ± 5.01	35.20 ± 4.80	19.90 ± 12.80	37.50 ± 4.80
P Used (g/d)	10.67 ± 2.33	15.00 ± 1.00	9.00 ± 7.00	19.00 ± 3.00
P Used (%)	28.43 ± 5.01	35.20 ± 4.80	19.90 ± 12.80	37.50 ± 4.80
Ca:P Ratio Digested*	1.63 ± 0.51	1.53 ± 0.34	2.38 ± 1.63	1.03 ± 0.03
Fecal Ca/Feed Ca: P Ratio	26.94 ± 2.34	27.70 ± 4.06	31.16 ± 8.85	37.27 ± 6.27
Fecal Ca/Feed P: Ca Ratio	77.96 ± 16.94	59.95 ± 33.15	74.82 ± 36.66	78.21 ± 47.21
Fecal P/Feed Ca: P Ratio	16.65 ± 2.34	20.32 ± 1.50	19.71 ± 0.29	24.71 ± 5.29
Fecal P/Feed P: Ca Ratio	42.59 ± 6.40	39.96 ± 15.21	44.16 ± 9.95	42.97 ± 12.96
P Digested (g/d)/ Feed P:Ca Ratio	15.49 ± 2.13	20.32 ± 3.82	14.43 ± 11.80	24.56 ± 2.56
Lactation (day)†	106.00 ± 5.19	60.00 ± 14.00	87.00 ± 4.00	146.00 ± 14.00
Age (year)†	3.00 ± 0.00	8.00 ± 0.00	7.00 ± 0.00	8.00 ± 0.00
Gestation (mo)†	0.50 ± 0.26	0.00 ± 0.00	0.25 ± 0.25	0.00 ± 0.00
Grain (kg/d)	0.00 ± 0.00	1.50 ± 0.00	0.00 ± 0.00	2.65 ± 0.00
Vitamin D_2 (IU/d)	0.00 ± 0.00	0.00 ± 0.00	320,000 ± 0.00	640,000 ± 0.00

* Based on g/d digested.
† At beginning of balance trial.
‡ Means in the same row not followed by the same letter are significantly different ($P<.05$).

Duncan's new multiple range test when appropriate. Results of least squares analysis of variance are shown in the tables and in the results for each experiment.

Following the description and results of the individual experiments, the overall effects of vitamin D_2 feeding and the relation of calcium and phosphorus intake and digestion on calcium and phosphorus utilization are discussed when appropriate. The average milk production for all the Jersey cow groups was 12.6 kg/d (range, 4.5 kg/d to 17.9 kg/d). The average dry matter intake was 12.0 kg/d (range, 9.8 kg/d to 16.5 kg/d). The average body weight was 397 kg (range, 322 kg to 464 kg).

Experiments 1A and 1B

In experiments 1A and 1B, the cows (Jerseys) were fed fresh green chopped alfalfa-brome grass soilage free choice with either no concentrate or with 0.9 kg to 2.65 kg of concentrate per day. The concentrate fed was ration No. 80 — ground shelled corn 227 kg, ground

TABLE 1B.—Effects of Vitamin D_2 and Grain Feeding in Cows Fed Second and Third Cutting Alfalfa-Brome Grass Soilage.

	No Grain No Vitamin D_2	No Grain + Vitamin D_2	Grain Fed No Vitamin D_2	Grain Fed + Vitamin D_2
No. of Cows (Trials)	3‡	2‡	1	1
Body Wt. (kg)	403.00 ± 10.00	356.00 ± 0.00	448.00	422.00
Milk (kg/d)	8.50 ± 0.38^{A}	11.65 ± 0.45^{B*}	13.40	13.60
Dry Matter Intake (kg/d)	13.53 ± 0.45	12.70 ± 0.40	16.50	15.30
Feed Ca (%)	2.25 ± 0.03	2.24 ± 0.04	2.18	2.05
Feed P (%)	0.35 ± 0.01	0.36 ± 0.02	0.35	0.35
Feed Ca:P Ratio	6.47 ± 0.23	6.30 ± 0.40	6.20	5.90
Feed P:Ca Ratio	0.16 ± 0.01	0.16 ± 0.01	0.16	0.17
Feces Ca (g/d)	212.00 ± 9.60	206.50 ± 1.50	200.00	202.00
Urine Ca (g/d)	3.97 ± 0.33	3.85 ± 0.85	4.20	3.10
Milk Ca (g/d)	17.00 ± 4.00	21.50 ± 0.50	30.00	30.00
Ca Outgo (g/d)	233.00 ± 13.05	232.00 ± 0.00	234.00	233.00
Ca Intake (g/d)	304.00 ± 12.00	283.50 ± 4.50	360.00	307.00
Ca Balance (g/d)	71.00 ± 3.79^{A}	51.50 ± 4.50^{B*}	126.00	74.00
Ca Digested (g/d)	91.67 ± 4.91	77.00 ± 6.00	160.00	105.00
Ca Digested (%)	30.17 ± 1.28	27.10 ± 1.70	44.40	34.20
Ca Used (g/d)	88.00 ± 5.13	73.00 ± 5.00	156.00	104.00
Ca Used (%)	28.97 ± 1.30	25.75 ± 1.35	43.30	33.90
Feces P (g/d)	26.33 ± 2.33	29.00 ± 3.00	23.00	27.00
Urine P (g/d)	0.48 ± 0.03	0.48 ± 0.50	0.60	0.57
Milk P (g/d)	10.33 ± 0.88	12.50 ± 0.50	17.00	16.00
P Outgo (g/d)	37.33 ± 2.67	42.00 ± 4.00	41.00	44.00
P Intake (g/d)	47.00 ± 2.08	45.00 ± 4.00	57.00	54.00
P Balance (g/d)	9.67 ± 0.88^{A}	3.00 ± 0.00^{B**}	16.00	10.00
P Digested (g/d)	20.66 ± 0.33^{A}	16.00 ± 1.00^{B*}	34.00	27.00
P Digested (%)	44.20 ± 2.55^{A}	35.65 ± 0.95^{B†}	59.60	50.00
P Used (g/d)	20.00 ± 0.58^{A}	15.50 ± 0.50^{B*}	33.00	26.00
P Used (%)	42.83 ± 3.17	34.65 ± 1.95	57.90	48.10
Ca:P Ratio Digested§	4.44 ± 0.27	4.81 ± 0.07	4.71	3.89
Fecal Ca/Feed Ca: P Ratio	32.83 ± 0.86	32.90 ± 1.85	32.26	34.24
Fecal Ca/Feed P: Ca Ratio	1325.00 ±109.60	1290.27 ± 90.40	1250.00	1188.24
Fecal P/Feed Ca: P Ratio	4.10 ± 0.50	4.65 ± 0.77	3.71	4.58
Fecal P/Feed P: Ca Ratio	167.00 ± 10.57	180.79 ± 7.45	143.75	158.82
P Digested (g/d)/ Feed P:Ca Ratio	132.55 ± 7.45	100.00 ± 0.00^{B*}	212.50	158.80
Lactation (day)‡‡	163.00 ± 7.75	150.00 ± 10.50	109.00	188.00
Age (year)‡‡	3.00 ± 0.00	7.00 ± 0.00	8.00	8.00
Gestation (mo)‡‡	2.00 ± 0.58	2.00 ± 0.50	0.00	0.00
Grain (kg/d)	0.00 ± 0.00	0.00 ± 0.00	0.90	1.80
Vitamin D_2 (IU/d)	0.00 ± 0.00	320,000 ± 0.00	0.00	640,000

‡ Means in the same row of columns 1 and 2 not followed by the same letter are significantly different (* = $P < .05$, ** = $P < .01$, † = $P < 10$). Columns 3 and 4 were not included in the analysis.

§ Based on g/d digested.

‡‡ At beginning of balance trial.

oats 227 kg, bone meal 4.54 kg, and iodized salt 4.54 kg. Experiment 1A involved cows fed first cutting soilage while second or third cutting soilage from the same fields, much higher in Ca and P, was fed to the cows in experiment 1B.

Cows fed no concentrate that were fed vitamin D received 320,000 I.U. of vitamin D_2 daily as 142 F irradiated dry yeast administered orally in gelatin capsules using a balling gun. Cows fed concentrate that were fed vitamin D received 640,000 I.U. of vitamin D_2 as 142 F irradiated dry yeast mixed in the concentrate at feeding time.

Five cows were used in these experiments involving 19 5-day digestion balance trials.

Results

The results are shown in Tables 1A and 1B as group means of all parameters measured plus standard errors. For each parameter, least squares analysis of variance revealed no significant interactions between vitamin D_2 and grain feeding (P>.05) in experiment 1A.

Significant increases due to grain feeding were found in milk production (P<.05); dry matter intake (P<.01); milk Ca (P<.10); Ca digested, g/d (P<.05); Ca digested, % (P<.01); Ca used, g/d (P<.05); Ca used, % (P<.10); urine P (P<.10); milk P (P<.05); P intake (P<.10); P digested, g/d (P<.10); and P used, g/d (P<.10).

No significant differences due to vitamin D_2 feeding were found, except that dry matter intake was significantly different (P<.05). The lack of effect of vitamin D_2 feeding in this experiment was likely associated with the negative Ca and P balances, and was likely related to the low P intake as well as the small sample numbers. These possibilities are considered later in a stepwise multiple regression involving all experiments.

No analysis of variance was done on experiment 1B except on the two no grain fed groups, as the grain fed groups consisted of only one cow each. In these groups a significant increase due to vitamin D_2 feeding was found in milk production (P<.05), and significant decreases were found in Ca balance (P<.05); P balance (P<.01); P digested, g/d (P<.05); P digested, % (P<.10); and P used, g/d (P<.05). Differences in other parameters measured were not significant or associated with vitamin D_2 feeding (Table 1B). However, sample numbers were small and variation was large, in some cases precluding definite conclusions.

Experiment 2

In experiment 2 the cows were fed green chopped alfalfa-brome grass soilage free choice. All cows were fed 1.25 kg to 1.50 kg of grain concentrate daily — ration No. 80 consisting of ground shelled corn 227 kg, ground oats 227 kg, bone meal 4.54 kg, and iodized salt 4.54 kg.

Three Jersey cows were used in nine 5-day balance trials in which first cutting soilage was used, six trials in which no vitamin D_2 was fed, and three trials in which vitamin D_2 was fed, 320,000 I.U./day. There were six balance trials in which second cutting soilage was fed, four in which no vitamin D_2 was fed, and two in which vitamin D_2 was fed at the rate of 320,000 I.U./d.

Results

The results shown in Table 2 are group means of all parameters measured with standard errors. Based on least squares analysis of variance, an interaction was observed between forage cutting number and vitamin D_2 feeding in dry matter intake (P<.05). Significant increases in means due to cutting number of the forage (first or second) were observed in feed Ca (P<.01); feed Ca:P (P<.05); fecal Ca (P<.01); urine Ca (P<.05); Ca excreted (P<.01); Ca intake (P<.01); fecal P (P<.05); urine P (P<.10); fecal Ca/P:Ca (P<.01); fecal Ca/Ca:P (P<.10); fecal P/P:Ca (P<.05); and Ca:P digested (P<.05). Decreases due to cutting number of the forage were observed in milk production (P<.05), milk Ca (P<.05), and feed P:Ca (P<.05). A significant increase in milk production (P<.05) and a decrease in urine Ca (P<.10) due to vitamin D_2 feeding were shown.

TABLE 2.—Effects on Ca and P Utilization of Feeding Vitamin D_2 to Cows Fed First and Second Cutting Alfalfa-Brome Grass Soilage.

	First Cutting		Second Cutting	
	No Vitamin D_2	Fed Vitamin D_2	No Vitamin D_2	Fed Vitamin D_2
No of Cows (Trials)	6	3	4	2
Body Wt. (kg)	388.67 ± 25.81	322.00 ± 1.73	394.75 ± 31.38	333.50 ± 5.50
Milk (kg/d)	13.15 ± 0.64^{A}‡	14.37 ± 0.72^{A}	8.80 ± 1.04^{B}	12.50 ± 1.90^{A}
Dry Matter Intake (kg/d)	12.08 ± 0.14^{B}	12.33 ± 0.26^{AB}	11.27 ± 0.35^{C}	13.15 ± 0.45^{A}
Feed Ca (%)	0.96 ± 0.04^{B}	0.99 ± 0.08^{B}	1.22 ± 0.07^{A}	1.11 ± 0.01^{AB}
Feed P (%)	0.34 ± 0.02	0.37 ± 0.03	0.36 ± 0.01	0.35 ± 0.02
Feed Ca:P Ratio	2.93 ± 0.09	2.71 ± 0.27	3.38 ± 0.27	3.21 ± 0.18
Feed P:Ca Ratio	0.35 ± 0.01	0.38 ± 0.04	0.30 ± 0.02	0.32 ± 0.02
Feces Ca (g/d)	85.68 ± 4.70^{B}	81.17 ± 5.15^{B}	107.70 ± 6.77^{A}	112.30 ± 6.70^{A}
Urine Ca (g/d)	1.07 ± 0.21^{B}	0.77 ± 0.18^{B}	2.03 ± 0.33^{A}	1.25 ± 0.25^{AB}
Milk Ca (g/d)	13.28 ± 0.99^{A}	13.20 ± 1.12^{A}	8.98 ± 0.58^{B}	12.20 ± 1.40^{AB}
Ca Outgo (g/d)	100.03 ± 5.71^{AB}	95.13 ± 6.26^{B}	118.70 ± 7.57^{AB}	125.75 ± 8.35^{A}
Ca Intake (g/d)	116.28 ± 3.68^{B}	111.87 ± 6.67^{B}	150.15 ± 9.60^{A}	146.20 ± 6.40^{A}
Ca Balance (g/d)	16.25 ± 4.46	16.73 ± 10.51	31.45 ± 8.32	20.45 ± 1.95
Ca Digested (g/d)	30.60 ± 3.99	30.70 ± 9.46	42.45 ± 7.85	33.90 ± 0.30
Ca Digested (%)	26.30 ± 3.20	27.13 ± 7.77	27.93 ± 3.86	23.15 ± 1.25
Ca Used (g/d)	29.53 ± 4.03	29.93 ± 9.44	40.43 ± 7.91	32.65 ± 0.55
Ca Used (%)	25.38 ± 3.28	26.30 ± 7.74	26.18 ± 4.34	26.80 ± 3.10
Feces P (g/d)	24.32 ± 1.45^{B}	26.43 ± 0.67^{AB}	29.58 ± 3.57^{AB}	35.05 ± 6.05^{A}
Urine P (g/d)	0.35 ± 0.16	0.33 ± 0.19	1.05 ± 0.49	1.00 ± 0.20
Milk P (g/d)	12.60 ± 1.39	13.63 ± 2.25	8.68 ± 0.65	13.05 ± 1.25
P Outgo (g/d)	37.27 ± 2.52	40.40 ± 2.70	39.30 ± 4.12	49.10 ± 4.60
P Intake (g/d)	39.83 ± 1.75	42.10 ± 4.62	44.70 ± 1.91	45.50 ± 0.50
P Balance (g/d)	2.57 ± 2.53	1.70 ± 7.29	5.40 ± 2.91	−3.60 ± 5.10
P Digested (g/d)	15.52 ± 1.41	15.67 ± 5.28	15.13 ± 2.56	10.45 ± 6.55
P Digested (%)	38.80 ± 2.87	35.47 ± 8.08	36.33 ± 4.86	22.70 ± 14.20
P Used (g/d)	15.17 ± 1.42	15.33 ± 5.09	14.08 ± 3.03	9.45 ± 6.35
P Used (%)	37.97 ± 2.89	34.70 ± 7.77	32.38 ± 7.51	20.65 ± 13.75
Ca:P Ratio Digested*	1.97 ± 0.17^{B}	2.03 ± 0.53^{AB}	3.07 ± 0.83^{AB}	5.32 ± 3.30^{A}
Fecal Ca/Feed Ca: P Ratio	29.20 ± 1.21	30.26 ± 1.62	32.31 ± 2.76	34.92 ± 0.18
Fecal Ca/Feed P: Ca Ratio	249.82 ± 21.68^{BC}	220.84 ± 33.38^{C}	366.06 ± 37.81^{A}	358.33 ± 38.33^{AB}
Fecal P/Feed Ca: P Ratio	8.34 ± 0.60	9.92 ± 0.79	6.56 ± 1.28	10.83 ± 1.29
Fecal P/Feed P: Ca Ratio	70.35 ± 4.86^{B}	71.50 ± 8.84^{AB}	100.07 ± 13.72^{AB}	112.44 ± 24.56^{A}
P Digested (g/d)/ Feed P:Ca Ratio	44.48 ± 3.62	39.79 ± 9.60	50.44 ± 7.38	32.26 ± 19.26
Lactation (day)†	108.00 ± 5.00	179.00 ± 8.00	173.00 ± 14.00	249.00 ± 27.00
Age (year)†	5.00 ± 0.50	3.00 ± 0.00	5.00 ± 0.60	3.00 ± 0.00
Gestation (mo)†	2.70 ± 0.23	5.80 ± 0.37	3.80 ± 0.32	7.90 ± 0.55
Grain (kg/d)	1.25 ± 0.11	1.50 ± 0.00	1.25 ± 0.14	1.50 ± 0.00
Vitamin D_2 (IU/d)	0.00 ± 0.00	320,000 ± 0.00	0.00 ± 0.00	320,000 ± 0.00

* Based on g/d digested.
† At beginning of balance trial.
‡ Means in the same row not followed by the same letter are significantly different ($P < .05$).

Experiment 3

In experiment 3, the cows were fed fresh chopped alfalfa-brome grass soilage free choice with approximately 2 kg of grain concentrate mixture No. 83 per day. The concentrate mixture consisted of ground shelled corn 227 kg, ground oats 161 kg, soybean meal (44% protein) 56.8 kg, iodized salt 4.54 kg, and bone meal 4.54 kg (crude protein of the mixture was approximately 16%).

Eight Jersey cows were used in 24 5-day trials, each cow being repeated on the same level of vitamin D_2 three times, during May, June and August. Six control trials were conducted on cows fed no vitamin D_2, six trials on cows fed 40,000 I.U. of vitamin D_2/day, six

TABLE 3.—Effects of Different Amounts of Vitamin D_2 Fed to Cows Receiving First or Second Cutting Alfalfa-Brome Grass Soilage on Ca and P Utilization.

	No Vitamin D_2	40,000 IU of Vitamin D_2/Day	80,000 IU of Vitamin D_2/Day	120,000 IU of Vitamin D_2/Day
No. of Cows (Trials)	6	6	6	6
Body Wt. (kg)	356.00 ± 18.77	350.00 ± 5.86	359.00 ± 9.37	404.00 ± 16.19
Milk (kg/d)	16.25 ± 0.80	17.80 ± 1.18	14.93 ± 1.78	17.05 ± 2.31
Dry Matter Intake (kg/d)	12.65 ± 1.11	12.53 ± 0.74	11.63 ± 0.92	12.73 ± 0.85
Feed Ca (%)	1.25 ± 0.10	1.49 ± 0.15	1.45 ± 0.20	1.25 ± 0.13
Feed P (%)	0.37 ± 0.01	0.36 ± 0.02	0.34 ± 0.03	0.38 ± 0.02
Feed Ca:P Ratio	3.47 ± 0.36	4.37 ± 0.74	4.80 ± 1.09	3.52 ± 0.65
Feed P:Ca Ratio	0.31 ± 0.03	0.26 ± 0.03	0.26 ± 0.04	0.32 ± 0.05
Feces Ca (g/d)	137.17 ± 26.59	146.17 ± 30.84	125.17 ± 26.66	125.33 ± 26.74
Urine Ca (g/d)	2.32 ± 1.07	2.22 ± 0.81	2.87 ± 1.23	2.93 ± 1.38
Milk Ca (g/d)	21.50 ± 2.26	22.83 ± 2.70	18.17 ± 2.43	20.67 ± 3.32
Ca Outgo (g/d)	160.83 ± 27.19	171.33 ± 29.73	146.33 ± 26.81	148.17 ± 24.95
Ca Intake (g/d)	162.67 ± 25.13	188.83 ± 26.63	168.00 ± 26.87	162.83 ± 24.91
Ca Balance (g/d)	1.83 ± 6.52	17.17 ± 5.11	21.67 ± 10.97	14.67 ± 5.51
Ca Digested (g/d)	25.50 ± 8.10	42.67 ± 7.15	41.17 ± 10.15	37.50 ± 8.05
Ca Digested (%)	17.80 ± 5.36	25.43 ± 5.96	28.20 ± 6.27	26.07 ± 5.71
Ca Used (g/d)	23.33 ± 8.48	41.67 ± 6.74	39.83 ± 9.69	34.00 ± 8.41
Ca Used (%)	16.70 ± 5.59	24.15 ± 6.00	26.73 ± 6.47	24.40 ± 5.92
Feces P (g/d)	31.00 ± 2.56	26.67 ± 2.99	23.50 ± 3.21	29.50 ± 2.50
Urine P (g/d)	0.17 ± 0.03	0.25 ± 0.13	0.27 ± 0.13	0.36 ± 0.26
Milk P (g/d)	12.67 ± 1.73	12.83 ± 1.89	11.33 ± 2.23	14.17 ± 3.24
P Outgo (g/d)	43.67 ± 2.09	39.67 ± 2.28	35.00 ± 3.84	44.00 ± 4.15
P Intake (g/d)	46.50 ± 2.99^{A}‡	44.50 ± 1.36^{AB}	37.83 ± 2.16^{B}	46.83 ± 2.97^{A}
P Balance (g/d)	2.83 ± 1.72	4.83 ± 1.25	2.83 ± 2.14	2.83 ± 2.21
P Digested (g/d)	15.50 ± 2.69	17.83 ± 1.78	14.33 ± 2.69	17.33 ± 1.94
P Digested (%)	32.88 ± 4.57	40.72 ± 4.98	38.27 ± 7.07	36.88 ± 3.53
P Used (g/d)	15.50 ± 2.69	17.67 ± 1.91	14.17 ± 2.83	17.00 ± 1.77
P Used (%)	32.88 ± 4.57	40.38 ± 5.23	37.85 ± 7.43	36.22 ± 3.24
Ca:P Ratio Digested*	1.54 ± 0.39	2.44 ± 0.34	3.52 ± 0.99	2.10 ± 0.39
Fecal Ca/Feed Ca: P Ratio	37.83 ± 3.99	32.88 ± 3.00	26.93 ± 3.61	34.79 ± 2.76
Fecal Ca/Feed P: Ca Ratio	516.29 ± 142.58	728.06 ± 300.49	668.88 ± 247.84	578.25 ± 200.39
Fecal P/Feed Ca: P Ratio	9.12 ± 0.51^{A}	6.65 ± 0.98^{AB}	5.73 ± 1.03^{B}	9.43 ± 1.30^{A}
Fecal P/Feed P: Ca Ratio	110.53 ± 19.75	115.63 ± 22.88	111.92 ± 29.87	104.02 ± 19.60
P Digested (g/d)/ Feed P:Ca Ratio	54.10 ± 11.99	74.56 ± 11.21	56.90 ± 9.32	56.84 ± 6.37
Lactation (day)†	126.00 ± 17.12	122.00 ± 23.00	103.00 ± 17.18	157.00 ± 33.56
Age (year)†	3.50 ± 0.22	4.00 ± 0.00	3.50 ± 0.22	5.80 ± 0.17
Gestation (mo)†	1.80 ± 0.60	1.50 ± 0.62	0.70 ± 0.42	2.00 ± 0.86
Grain (kg/d)	1.97 ± 0.25	2.07 ± 0.21	1.57 ± 0.11	1.95 ± 0.24
Vitamin D_2 (IU/d)	0.00 ± 0.00	40,000 ± 0.00	80,000 ± 0.00	120,000 ± 0.00

*Based on g/d digested.

†At beginning of balance trial.

‡Means in the same row not followed by the same letter are significantly different ($P<.05$). Actual probability based on least squares analysis of variance for amount of vitamin D_2 were for P intake ($P=0.0604$) and for fecal P/Ca:P ratio ($P=0.0387$). Other parameters were not significantly different.

trials on cows fed 80,000 I.U. of vitamin D_2/day, and six trials on cows fed 120,000 I.U. of vitamin D_2/day.

Results

The results are shown in Table 3 as group means of all parameters measured plus standard errors. Least squares analysis of variance revealed no significant differences among the group means in this experiment due to level of vitamin D_2 fed except phosphorus intake ($P<.10$) and fecal P/Ca:P ($P<.05$).

Experiment 4

In experiment 4, seven Jersey cows were used in seven digestion balance trials. Two cows were fed no vitamin D_2, two cows were fed 40,000 I.U. of vitamin D_2 per day, two cows were fed 80,000 I.U. of vitamin D_2 per day, and one cow was fed 120,000 I.U. of vitamin D_2 per day.

All cows were fed alfalfa hay free choice and an average of 1.77 kg of grain concentrate/day. This was

TABLE 4.—Effects of Feeding Different Amounts of Vitamin D_2 on Ca and P Utilization.

	No Vitamin D_2	40,000 IU/Day Vitamin D_2	80,000 IU/Day Vitamin D_2	120,000 IU/Day Vitamin D_2
No. of Cows (Trials)	2	2	2	1
Body Wt. (kg)	365.00 ± 45.00	347.00 ± 19.00	356.50 ± 18.50	363.00
Milk (kg)	12.15 ± 0.85	13.05 ± 0.15	11.85 ± 2.85	11.70
Dry Matter Intake (kg/d)	13.00 ± 1.00‡	13.20 ± 0.00	12.30 ± 1.90	13.70
Feed Ca (%)	1.84 ± 0.03	1.85 ± 0.01	1.91 ± 0.02	1.84
Feed P (%)	0.26 ± 0.02	0.27 ± 0.02	0.24 ± 0.00	0.24
Feed Ca:P Ratio	7.25 ± 0.55	7.00 ± 0.40	7.95 ± 0.05	7.60
Feed P:Ca Ratio	0.14 ± 0.01	0.14 ± 0.01	0.13 ± 0.00	0.13
Feces Ca (g/d)	163.00 ± 3.00	148.50 ± 4.50	141.50 ± 34.50	160.00
Urine Ca (g/d)	7.00 ± 0.40	4.80 ± 4.00	8.00 ± 1.70	3.20
Milk Ca (g/d)	15.00 ± 1.00	16.00 ± 1.00	14.50 ± 3.50	15.00
Ca Outgo (g/d)	185.00 ± 4.00	169.00 ± 7.50	164.00 ± 40.00	178.00
Ca Intake (g/d)	240.00 ± 16.00	244.50 ± 2.50	235.50 ± 37.50	253.00
Ca Balance (g/d)	55.00 ± 12.00	75.00 ± 5.00	71.50 ± 2.50	75.00
Ca Digested (g/d)	77.00 ± 13.00	96.00 ± 2.00	94.00 ± 3.00	93.00
Ca Digested (%)	31.80 ± 3.30	39.20 ± 1.20	40.70 ± 5.20	36.70
Ca Used (g/d)	70.00 ± 13.00	91.00 ± 6.00	86.00 ± 1.00	90.00
Ca Used (%)	28.90 ± 3.50	37.20 ± 2.80	37.40 ± 5.50	35.60
Feces P (g/d)	21.00 ± 5.00	21.50 ± 1.50	19.00 ± 3.00	22.00
Urine P (g/d)	0.08 ± 0.01	0.08 ± 0.03	0.07 ± 0.02	0.07
Milk P (g/d)	6.50 ± 0.50	7.00 ± 0.00	6.50 ± 1.50	7.00
P. Outgo (g/d)	27.50 ± 5.50	28.50 ± 1.50	25.50 ± 4.50	29.00
P. Intake (g/d)	33.50 ± 4.50	34.00 ± 2.00	30.00 ± 5.00	33.00
P Balance (g/d)	6.00 ± 1.00	5.50 ± 0.50	4.50 ± 0.50	4.00
P Digested (g/d)	12.50 ± 0.50	12.50 ± 0.50	11.00 ± 2.00	11.00
P Digested (%)	38.15 ± 6.65	36.80 ± 0.70	36.55 ± 0.55	33.30
P Used (g/d)	12.50 ± 0.50	12.50 ± 0.50	11.00 ± 2.00	11.00
P Used (%)	38.15 ± 6.65	36.80 ± 0.70	36.55 ± 0.55	33.30
Ca:P Ratio Digested*	6.21 ± 1.29	7.69 ± 0.15	8.79 ± 1.32	8.45
Fecal Ca/Feed Ca: P Ratio	22.64 ± 2.13	21.25 ± 0.57	17.77 ± 4.23	21.05
Fecal Ca/Feed P: Ca Ratio	1168.72 ± 62.05	1068.46 ± 108.46	1088.46 ± 265.38	1230.77
Fecal P/Feed Ca: P Ratio	2.97 ± 0.91	3.09 ± 0.39	2.39 ± 0.36	2.89
Fecal P/Feed P: Ca Ratio	148.21 ± 25.13	153.59 ± 0.25	146.15 ± 23.08	169.23
P Digested (g/d)/ Feed P:Ca Ratio	90.00 ± 10.00	89.49 ± 2.82	84.62 ± 15.38	84.62
Lactation (day)†	191.00 ± 9.00	186.50 ± 35.50	167.50 ± 9.50	261.00
Age (year)†	3.50 ± 0.50	4.00 ± 0.00	3.50 ± 0.50	6.00
Gestation (mo)†	3.50 ± 0.50	3.00 ± 1.00	2.00 ± 0.00	4.00
Grain (kg/d)	2.27 ± 0.91	2.55 ± 0.64	1.41 ± 0.41	1.63
Vitamin D_2 (IU/d)	0.00 ± 0.00	40,000 ± 0.00	80,000 ± 0.00	120,000

*Based on g/d digested.
†At beginning of balance trial.
‡None of the differences among means were significant ($P < .05$).

the same grain concentrate mixture (No. 83) used in experiment 3.

Results

The results are shown in Table 4 as group means with standard errors. None of the means were significantly different due to level of vitamin D_2 feeding as determined by least squares analysis of variance. This was likely due to the small sample number and large within group variation.

Experiments 5A and 5B

In experiment 5, three Jersey cows were used in 12 balance trials comparing cows fed no grain concentrate with cows fed grain concentrate. A comparison of grain fed cows also was made with cows fed either no vitamin D_2, 80,000 I.U. of vitamin D_2 per day, or 160,000 I.U. of vitamin D_2 per day. When grain concentrate was fed, the amount was 3.6 kg/day. The grain concentrate was ration No. 82, consisting of ground shelled corn 359 kg, soybean meal 90.9 kg, and iodized salt 4.54

TABLE 5A.—Effects of Feeding Grain Concentrate on Utilization of Calcium and Phosphorus in Lactating Cows.

	Experiment 5A	
	No Grain No Vitamin D_2	Grain Fed No Vitamin D_2
No. of Cows (Trials)	3	3
Body Wt. (kg)	395.33 ± 24.58	419.00 ± 31.19
Milk (kg/d)	7.30 ± 1.41	7.20 ± 1.81
Dry Matter Intake (kg/d)	12.23 ± 0.76‡	14.37 ± 0.71
Feed Ca (%)	1.20 ± 0.00^{C}	1.00 ± 0.01^{D}
Feed P (%)	0.24 ± 0.00^{A}	0.29 ± 0.00^{B}
Feed Ca:P Ratio	5.10 ± 0.06^{C}	3.47 ± 0.03^{D}
Feed P:Ca Ratio	0.20 ± 0.00^{C}	0.29 ± 0.01^{D}
Feces Ca (g/d)	144.80 ± 14.62	130.17 ± 13.16
Urine Ca (g/d)	1.27 ± 0.09	1.43 ± 0.07
Milk Ca (g/d)	11.27 ± 3.12	9.47 ± 2.59
Ca Outgo (g/d)	157.33 ± 17.75	141.07 ± 15.18
Ca Intake (g/d)	147.13 ± 9.17	142.93 ± 8.30
Ca Balance (g/d)	−10.20 ± 8.60	1.87 ± 8.09
Ca Digested (g/d)	2.33 ± 5.52	12.77 ± 7.05
Ca Digested (%)	2.07 ± 4.09	9.23 ± 4.93
Ca Used (g/d)	1.07 ± 5.60^{E}	15.97 ± 3.25^{F}
Ca Used (%)	1.63 ± 4.14	8.20 ± 4.94
Feces P (g/d)	19.00 ± 2.87	24.10 ± 1.66
Urine P (g/d)	0.90 ± 0.06	1.47 ± 0.35
Milk P (g/d)	7.67 ± 1.45	7.70 ± 2.05
P Outgo (g/d)	27.57 ± 3.91	33.27 ± 3.64
P Intake (g/d)	28.83 ± 1.65^{A}	41.17 ± 2.21^{B}
P Balance (g/d)	1.27 ± 2.26^{E}	7.90 ± 1.50^{F}
P Digested (g/d)	9.83 ± 1.37^{C}	17.07 ± 0.55^{D}
P Digested (%)	34.83 ± 6.21	41.67 ± 0.99
P Used (g/d)	8.93 ± 1.32^{C}	15.60 ± 0.56^{D}
P Used (%)	36.67 ± 1.27	38.03 ± 1.12
Ca:P Ratio Digested*	0.24 ± 0.54	0.75 ± 0.42
Fecal Ca/Feed Ca:P Ratio	28.35 ± 2.68	37.50 ± 3.55
Fecal Ca/Feed P:Ca Ratio	737.39 ± 77.74^{A}	449.58 ± 47.51^{B}
Fecal P/Feed Ca:P Ratio	3.72 ± 0.56	6.94 ± 0.42
Fecal P/Feed P:Ca Ratio	96.55 ± 14.10^{C}	83.31 ± 6.76^{D}
P Digested (g/d)/Feed P:Ca Ratio	50.16 ± 7.42	58.94 ± 2.65
Lactation (day)†	182.00 ± 22.91	196.00 ± 22.91
Age (year)†	5.60 ± 1.18	5.70 ± 1.18
Gestation (mo)†	3.33 ± 0.33	4.33 ± 0.33
Grain (kg/d)	0.00 ± 0.00	3.60 ± 0.00
Vitamin D_2 (IU/d)	0.00 ± 0.00	0.00 ± 0.00

*Based on g/d digested.
†At beginning of balance trial.
‡Means in the same row not followed by the same letter are significantly different, A and B ($P<.05$), C and D ($P<.01$), E and F ($P<.10$).

kg. The roughage portion of the ration was 1.36 kg/day of alfalfa hay and alfalfa pellets (5/8 inch coarsely ground) fed free choice.

Results

The results of this experiment are shown in Tables 5A and 5B as group means with standard errors. Least squares analysis of variance was performed on both comparisons, grain vs. no grain and effect of level of vitamin D_2 in grain fed cows.

In the grain vs. no grain comparison (Table 5A), least squares analysis of variance showed significant increases due to grain feeding in feed P ($P<.05$); Ca used, g/d ($P<.10$); P intake ($P<.05$); P balance ($P<.10$); P digested ($P<.01$); P used, g/d ($P<.01$); feed P:Ca ($P<.01$). Decreases due to grain feeding were observed in feed Ca ($P<.01$): feed Ca:P ($P<.01$); fecal Ca/P:Ca ($P<.05$); and fecal P/P:Ca ($P<.01$). The differences likely reflected the higher phosphorus intake due to grain feeding which increased from 28.83 ± 1.67 g/d in the no grain fed group to 41.17 ± 2.21 g/d in the grain fed group.

When cows fed no vitamin D_2 were compared with cows fed vitamin D_2 at either 80,000 I.U./day or 160,000

TABLE 5B.—Effects of Feeding Two Levels of Vitamin D_2 on Calcium and Phosphorus Utilization in Lactating Cows.

	Experiment 5B		
	Grain Fed No Vitamin D_2	Grain Fed + 80,000 IU/d Vitamin D_2	Grain Fed + 160,000 IU/d Vitamin D_2
No. of Cows (Trials)	3	3	2
Body Wt. (kg)	419.00 ± 31.19	424.67 ± 25.10	445.00 ± 41.00
Milk (kg/d)	7.20 ± 1.81	6.50 ± 1.90	4.50 ± 3.00
Dry Matter Intake (kg/d)	14.37 ± 0.71	12.77 ± 1.33	12.50 ± 2.30
Feed Ca (%)	1.00 ± 0.01[A‡]	0.86 ± 0.04[B]	1.07 ± 0.01[A]
Feed P (%)	0.29 ± 0.00	0.26 ± 0.00	0.29 ± 0.02
Feed Ca:P Ratio	3.47 ± 0.03[A]	3.00 ± 0.12[B]	3.70 ± 0.20[A]
Feed P:Ca Ratio	0.29 ± 0.01	0.31 ± 0.02	0.28 ± 0.02
Feces Ca (g/d)	130.17 ± 13.16	110.07 ± 8.93	96.50 ± 15.00
Urine Ca (g/d)	1.43 ± 0.17	1.73 ± 0.38	2.15 ± 0.25
Milk Ca (g/d)	9.47 ± 2.59	8.17 ± 2.66	5.30 ± 3.70
Ca Outgo (g/d)	141.07 ± 15.18	119.97 ± 10.83	105.95 ± 18.95
Ca Intake (g/d)	142.93 ± 8.30	110.50 ± 16.64	133.90 ± 25.50
Ca Balance (g/d)	1.87 ± 8.09[AB]	−9.46 ± 6.27[B]	27.95 ± 4.55[A]
Ca Digested (g/d)	12.77 ± 7.05[AB]	0.43 ± 7.72[B]	35.40 ± 8.50[A]
Ca Digested (%)	9.23 ± 4.93[AB]	−1.53 ± 6.55[B]	26.10 ± 1.80[A]
Ca Used (g/d)	15.97 ± 3.25[AB]	−1.30 ± 7.43[B]	33.25 ± 8.25[A]
Ca Used (%)	8.20 ± 4.94[AB]	−3.13 ± 6.56[B]	24.50 ± 1.90[A]
Feces P (g/d)	24.10 ± 1.66	25.07 ± 2.70	22.80 ± 4.20
Urine P (g/d)	1.47 ± 0.35[A]	0.18 ± 0.05[B]	0.20 ± 0.11[B]
Milk P (g/d)	7.70 ± 2.05	7.20 ± 2.25	5.20 ± 3.70
P Outgo (g/d)	33.27 ± 3.64	34.07 ± 4.32	29.95 ± 6.85
P Intake (g/d)	41.17 ± 2.21	33.43 ± 3.30	35.95 ± 4.65
P Balance (g/d)	7.90 ± 1.50[A]	−0.63 ± 2.08[B]	6.90 ± 3.10[AB]
P Digested (g/d)	17.07 ± 0.55[A]	8.37 ± 0.62[C]	13.15 ± 0.45[B]
P Digested (%)	41.67 ± 0.99[A]	25.23 ± 0.80[B]	37.00 ± 3.50[A]
P Used (g/d)	15.60 ± 0.56[A]	6.57 ± 1.08[C]	12.10 ± 0.60[B]
P Used (%)	38.03 ± 1.12[A]	19.43 ± 1.43[C]	31.15 ± 0.15[B]
Ca:P Ratio Digested*	0.75 ± 0.42	−0.05 ± 0.87	2.69 ± 0.56
Fecal Ca/Feed Ca:P Ratio	37.50 ± 3.55	36.98 ± 4.30	26.48 ± 2.62
Fecal Ca/Feed PCa Ratio	449.58 ± 47.51	359.84 ± 48.59	362.23 ± 74.30
Fecal P/Feed Ca:P Ratio	6.94 ± 0.42	8.43 ± 1.20	6.12 ± 0.80
Fecal P/Feed P:Ca Ratio	83.31 ± 6.76	82.17 ± 13.30	83.99 ± 19.85
P Digested (g/d)/Feed P:Ca Ratio	58.94 ± 2.65[A]	27.33 ± 3.48[B]	48.05 ± 4.26[A]
Lactation (day)†	196.00 ± 22.91	206.00 ± 22.91	232.00 ± 30.00
Age (year)†	5.70 ± 1.18	5.70 ± 1.18	4.70 ± 1.10
Gestation (mo)†	4.33 ± 0.33	4.33 ± 0.33	4.50 ± 0.50
Grain (kg/d)	3.60 ± 0.00	3.60 ± 0.00	3.60 ± 0.00
Vitamin D_2 (IU/d)	0.00 ± 0.00	80,000 ± 0.00	160,000 ± 0.00

* Based on g/d digested.
† At beginning of balance trial.
‡ Means in the same row not followed by the same letter are significantly different ($P<.05$).

I.U./day (Table 5B), least squares analysis of variance showed significant differences due to vitamin D feeding in Ca balance (P<.05); Ca digested, g/d (P<.10); Ca digested, % (P<.10); Ca used, g/d (P<.05); Ca used, % (P<.10); feed Ca (P<.01); feed Ca:P (P<.05); urine P (P<.05); P balance (P<.10); P digested, g/d (P<.01); P digested, % (P<.01); P used, g/d (P<.01); and P used, % (P<.01).

Experiment 6

In experiment 6, two kinds of alfalfa pellets were compared with or without 512,000 I.U. of vitamin D per day. The "Denman" alfalfa pellets (Denmandale Farms, Cortland, Ohio) were 1.91 cm in diameter while the "Poppe" alfalfa pellets (Bremco Alfalfa Mills, Inc., New Breman, Ohio) were 0.64 cm in diameter. In addition to pellets fed approximately free choice, 1.8 kg of alfalfa hay and 3.6 kg of grain concentrate were fed daily. The concentrate mixture (ration No. 79) consisted of ground shelled corn 272.7 kg, coarsely ground oats 136.4 kg, soybean meal 45.56 kg, iodized salt 4.54 kg, and bone meal 4.54 kg. Eight Jersey cows were used in 14 digestion balance trials in this experiment.

Results

Table 6 shows the group means with standard errors for all parameters measured. Based on least squares analysis of variance, interactions were observed between vitamin D_2 feeding and kind of pellets in feed Ca (P<.05) and feed Ca:P (P<.05). Significant increases due to vitamin D_2 feeding were noted in Ca balance (P<.05); Ca digested, g/d (P<.05); Ca digested, % (P<.01); Ca used, g/d (P<.05); and Ca used, % (P<.01). Decreases were observed in fecal Ca (P<.10); fecal Ca/P:Ca (P<.10); and fecal Ca/Ca:P (P<.05).

Many of the parameters measured were significantly different due to the kind of pellets (Denman or Poppe) fed. The Denman pellets were higher in feed P (P<.01); dry matter intake (P<.05); fecal Ca (P<.05); urine Ca (P<.01); Ca outgo (P<.05); milk P (P<.01); P outgo (P<.10); P intake (P<.01); P balance (P<.05); P digested, g/d (P<.01); P digested, % (P<.05); P used, g/d (P<.01); P used, % (P<.05); feed P:Ca (P<.01); fecal Ca/Ca:P (P<.01); and fecal P/Ca:P (P<.05).

Poppe pellets were higher in Ca balance (P<.01); Ca digested, g/d (P<.05); Ca digested, % (P<.01); Ca used, g/d (P<.05); Ca used, % (P<.01); urine P (P<.01); fecal P/P:Ca (P<.05); and Ca:P ratio digested (P<.01).

TABLE 6.—Effects of Vitamin D_2 on Ca and P Utilization in Cows Fed Pelleted Alfalfa.

	Denman Pellets No Vitamin D_2	Poppe Pellets No Vitamin D_2	Denman Pellets + Vitamin D_2	Poppe Pellets + Vitamin D_2
No. of Cows (Trials)	2	4	4	4
Body Wt. (kg)	421.00 ± 8.00	382.50 ± 4.91	420.25 ± 27.68	382.50 ± 4.91
Milk (kg/d)	11.35 ± 2.65	10.58 ± 0.33	10.28 ± 1.13	10.20 ± 0.19
Dry Matter Intake (kg/d)	14.00 ± 0.70	11.95 ± 0.28	13.55 ± 1.10	12.15 ± 0.21
Feed Ca (%)	0.78 ± 0.01^{B}‡	0.93 ± 0.01^{A}	0.82 ± 0.01^{B}	0.92 ± 0.00^{A}
Feed P (%)	0.50 ± 0.01^{A}	0.46 ± 0.01^{B}	0.49 ± 0.01^{A}	0.46 ± 0.00^{B}
Feed Ca:P Ratio	1.55 ± 0.50^{C}	2.00 ± 0.00^{A}	1.65 ± 0.03^{B}	2.00 ± 0.00^{A}
Feed P:Ca Ratio	0.64 ± 0.02^{A}	0.50 ± 0.01^{B}	0.61 ± 0.01^{A}	0.50 ± 0.01^{B}
Feces Ca (g/d)	66.50 ± 4.50^{A}	61.25 ± 2.21^{A}	62.50 ± 5.72^{A}	48.75 ± 1.93^{B}
Urine Ca (g/d)	2.85 ± 0.05^{A}	1.78 ± 0.14^{B}	3.13 ± 0.22^{A}	2.10 ± 0.07^{B}
Milk Ca (g/d)	16.00 ± 5.00	12.25 ± 0.48	13.25 ± 2.17	12.25 ± 0.48
Ca Outgo (g/d)	85.50 ± 9.50^{A}	75.25 ± 2.56^{AB}	79.00 ± 7.63^{AB}	63.00 ± 1.68^{B}
Ca Intake (g/d)	109.50 ± 6.50	110.25 ± 2.69	110.25 ± 8.62	111.00 ± 2.35
Ca Balance (g/d)	24.00 ± 3.00^{B}	35.00 ± 4.95^{B}	31.25 ± 1.44^{B}	48.00 ± 3.11^{A}
Ca Digested (g/d)	43.00 ± 2.00^{B}	49.00 ± 4.69^{B}	47.75 ± 3.20^{B}	62.25 ± 2.95^{A}
Ca Digested (%)	39.20 ± 0.20^{B}	44.38 ± 3.32^{B}	43.50 ± 1.10^{B}	56.02 ± 1.93^{A}
Ca Used (g/d)	40.00 ± 2.00^{B}	47.25 ± 4.55^{B}	44.50 ± 3.23^{B}	60.25 ± 2.95^{A}
Ca Used (%)	36.45 ± 0.25^{B}	42.50 ± 3.07^{B}	40.45 ± 0.92^{B}	54.20 ± 1.90^{A}
Feces P (g/d)	34.00 ± 2.00	36.25 ± 0.75	35.50 ± 4.29	31.00 ± 2.12
Urine P (g/d)	0.55 ± 0.15^{B}	0.93 ± 0.05^{A}	0.50 ± 0.07^{B}	0.93 ± 0.06^{A}
Milk P (g/d)	13.00 ± 3.00^{A}	6.50 ± 0.29^{B}	11.50 ± 1.50^{A}	6.50 ± 0.29^{B}
P Outgo (g/d)	47.55 ± 5.15	43.75 ± 0.85	45.00 ± 3.16	38.50 ± 2.10
P Intake (g/d)	69.00 ± 3.00^{A}	55.25 ± 0.75^{B}	66.75 ± 5.42^{A}	55.25 ± 0.75^{B}
P Balance (g/d)	21.45 ± 2.15^{A}	11.00 ± 1.29^{A}	21.80 ± 2.75^{A}	16.75 ± 2.84^{AB}
P Digested (g/d)	35.00 ± 1.00^{A}	19.00 ± 1.47^{C}	31.25 ± 3.25^{AB}	24.25 ± 2.87^{BC}
P Digested (%)	50.75 ± 0.75^{A}	34.73 ± 2.26^{B}	46.98 ± 3.65^{A}	43.70 ± 4.84^{AB}
P Used (g/d)	34.45 ± 0.85^{A}	18.00 ± 1.47^{C}	30.80 ± 3.19^{AB}	23.25 ± 2.87^{BC}
P Used (%)	49.95 ± 0.95^{A}	32.48 ± 2.22^{B}	46.30 ± 3.58^{A}	41.88 ± 4.60^{AB}
Ca:P Ratio Digested*	1.23 ± 0.22^{B}	2.57 ± 0.06^{A}	1.55 ± 0.08^{B}	2.64 ± 0.22^{A}
Fecal Ca/Feed Ca: P Ratio	42.85 ± 1.52^{A}	30.63 ± 1.11^{B}	38.01 ± 3.87^{A}	24.38 ± 0.97^{B}
Fecal Ca/Feed P: Ca Ratio	104.95 ± 9.57^{AB}	121.81 ± 2.91^{A}	103.16 ± 8.77^{AB}	97.57 ± 4.32^{B}
Fecal P/Feed Ca: P Ratio	21.92 ± 0.58	18.13 ± 0.38	21.65 ± 2.95	15.50 ± 1.06
Fecal P/Feed P: Ca Ratio	53.65 ± 4.12^{B}	72.14 ± 0.72^{A}	58.44 ± 6.33^{B}	61.88 ± 3.58^{AB}
P Digested (g/d)/ Feed P:Ca Ratio	55.19 ± 2.88	37.98 ± 3.55	51.74 ± 5.69	48.71 ± 6.29
Lactation (day)†	217.50 ± 13.50	153.50 ± 31.02	232.50 ± 16.70	185.50 ± 31.32
Age (year)†	6.50 ± 0.50	4.00 ± 0.58	7.50 ± 2.52	4.00 ± 0.58
Gestation (mo)†	4.50 ± 0.50	0.50 ± 0.29	5.00 ± 0.41	1.25 ± 0.75
Grain (kg/d)	3.60 ± 0.00	3.60 ± 0.00	3.60 ± 0.37	3.60 ± 0.00
Vitamin D_2 (IU/d)	0.00 ± 0.00	0.00 ± 0.00	512,000 ± 0.00	512,000 ± 0.00

*Based on g/d digested.
† At beginning of balance trial.
‡ Means in the same row not followed by the same letter are significantly different ($P<.05$).

Experiment 7

In experiment 7, 10 Jerseys and 10 Holstein cows in peak lactation were used in 20 7-day digestion balance trials to measure the effects of feeding vitamin D_2 on calcium and phosphorus utilization. The cows were fed alfalfa hay free choice plus an average of 5.84 kg of grain concentrate mixture No. 35A consisting of corn and cob meal 254.6 kg, ground oats 136.4 kg, wheat bran 45.5 kg, soybean meal 68.2 kg, salt 4.54 kg, and bone meal 4.55 kg. The cows averaged 39 days of lactation at the beginning of the balance trials. One-half the cows were fed vitamin D_2, average amount 362,000 I.U./day mixed in the grain concentrate at feeding time.

Results

The results are shown as group means of the parameters measured plus standard errors in Table 7 for both breeds fed vitamin D_2 or no vitamin D_2. Least squares analysis of variance revealed no significant differences due to vitamin D_2 feeding nor was there any interaction between vitamin D_2 feeding and breed. The expected differences due to breed were observed mostly related to body size and feed intake.

TABLE 7.—Effects of Vitamin D_2 Feeding on Ca and P Utilization at Peak Lactation.

	Holstein No Vitamin D_2	Holstein + Vitamin D_2	Jersey No Vitamin D_2	Jersey + Vitamin D_2
No. of Cows (Trials)	5	5	5	5
Body Wt. (kg)	522.60 ± 42.21	538.00 ± 22.55	365.00 ± 36.69	315.80 ± 30.01
Milk (kg/d)	27.08 ± 3.34^{A}‡	24.58 ± 3.01^{A}	15.00 ± 1.85^{B}	15.92 ± 0.81^{B}
Dry Matter Intake (kg/d)	15.16 ± 1.53^{A}	15.20 ± 0.64^{A}	10.44 ± 0.41^{B}	10.98 ± 0.50^{B}
Feed Ca (%)	1.01 ± 0.09	1.05 ± 0.13	1.06 ± 0.12	1.06 ± 0.13
Feed P (%)	0.41 ± 0.02	0.44 ± 0.03	0.46 ± 0.02	0.42 ± 0.02
Feed Ca:P Ratio	2.32 ± 0.16	2.38 ± 0.25	2.26 ± 0.25	2.48 ± 0.23
Feed P:Ca Ratio	0.42 ± 0.03	0.44 ± 0.06	0.45 ± 0.05	0.42 ± 0.04
Feces Ca (g/d)	97.60 ± 4.76^{A}	81.60 ± 8.10^{AB}	60.40 ± 7.53^{B}	64.20 ± 6.44^{B}
Urine Ca (g/d)	2.04 ± 0.53	2.28 ± 0.29	1.36 ± 0.21	1.68 ± 0.37
Milk Ca (g/d)	29.20 ± 3.97^{AB}	32.80 ± 4.84^{A}	19.00 ± 2.02^{B}	18.80 ± 1.39^{B}
Ca Outgo (g/d)	129.00 ± 6.28	116.80 ± 4.72	80.80 ± 6.72	84.80 ± 6.52
Ca Intake (g/d)	149.80 ± 12.87^{AB}	157.40 ± 16.43^{A}	110.20 ± 12.99^{B}	114.20 ± 11.24^{B}
Ca Balance (g/d)	20.80 ± 8.20	40.60 ± 12.62	29.40 ± 9.70	29.40 ± 12.54
Ca Digested (g/d)	52.20 ± 10.37	76.00 ± 11.22	49.80 ± 7.75	50.20 ± 12.00
Ca Digested (%)	33.78 ± 4.09	47.42 ± 2.37	44.82 ± 4.54	41.96 ± 8.60
Ca Used (g/d)	48.00 ± 11.10	73.40 ± 11.17	48.40 ± 7.85	48.20 ± 11.93
Ca Used (%)	30.82 ± 4.87	45.96 ± 3.47	43.46 ± 4.79	40.64 ± 8.87
Feces P (g/d)	37.80 ± 4.31^{A}	35.80 ± 1.80^{AB}	25.80 ± 2.56^{BC}	24.40 ± 4.06^{C}
Urine P (g/d)	0.16 ± 0.04	0.52 ± 0.35	0.62 ± 0.35	0.18 ± 0.08
Milk P (g/d)	25.40 ± 3.85^{AB}	26.80 ± 4.12^{A}	16.60 ± 2.32^{B}	17.20 ± 1.59^{AB}
P Outgo (g/d)	63.20 ± 6.91^{A}	63.00 ± 4.85^{A}	42.80 ± 2.89^{B}	41.80 ± 5.24^{B}
P Intake (g/d)	63.60 ± 3.49^{A}	67.40 ± 6.77^{A}	47.60 ± 1.63^{B}	46.20 ± 1.28^{B}
P Balance (g/d)	0.40 ± 5.42	4.40 ± 9.01	6.80 ± 4.51	4.40 ± 6.29
P Digested (g/d)	25.80 ± 4.18	31.60 ± 6.93	21.80 ± 2.37	21.80 ± 5.21
P Digested (%)	40.02 ± 5.54	44.50 ± 7.01	45.82 ± 4.92	46.18 ± 9.73
P Used (g/d)	25.80 ± 4.18	31.20 ± 6.83	21.40 ± 2.09	19.60 ± 5.64
P Used (%)	40.02 ± 5.54	43.94 ± 6.82	44.96 ± 4.19	45.76 ± 9.75
Ca:P Ratio Digested*	2.07 ± 0.26	2.98 ± 0.68	2.43 ± 0.42	2.68 ± 0.72
Fecal Ca/Feed Ca: P Ratio	42.59 ± 2.73	35.77 ± 5.09	26.74 ± 1.91	27.07 ± 4.66
Fecal Ca/Feed P: Ca Ratio	238.42 ± 22.96^{A}	196.56 ± 34.32^{AB}	145.57 ± 28.95^{B}	158.74 ± 20.79^{AB}
Fecal P/Feed Ca: P Ratio	16.89 ± 2.96^{A}	16.23 ± 2.88^{A}	11.73 ± 1.33^{A}	10.53 ± 2.22^{A}
Fecal P/Feed P: Ca Ratio	89.69 ± 5.43^{A}	83.51 ± 6.09^{AB}	61.31 ± 10.45^{B}	59.01 ± 10.14^{B}
P Digested (g/d)/ Feed P:Ca Ratio	61.37 ± 12.98	72.90 ± 15.17	49.76 ± 5.77	55.45 ± 15.92
Lactation (day)†	46.20 ± 8.95	39.20 ± 6.40	33.00 ± 6.49	38.40 ± 3.47
Age (year)†	4.06 ± 0.86	3.62 ± 0.87	3.86 ± 0.82	3.12 ± 0.57
Gestation (mo)†	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Grain (kg/d)	6.60 ± 0.43	6.58 ± 0.34	5.10 ± 0.24	5.10 ± 0.24
Vitamin D_2 (IU/d)	0.00 ± 0.00	365,600 ± 12,624	0.00 ± 0.00	358,400 ± 15,677

* Based on g/d digested.
† At beginning of balance trial.
‡ Means in the same row not followed by the same letter are significantly different (P<.05).

TABLE 8A.—Effects of Feeding Bacitracin-Treated Legume-Grass Silage vs. Untreated Silage on Ca and P Utilization in Lactating Cows Fed Either Corn, Soybran Flakes, or Beet Pulp as the Energy Source in the Concentrate.

	Untreated Silage			Treated Silage		
	Corn	Soybran Flakes	Beet Pulp	Corn	Soybran Flakes	Beet Pulp
No. of Cows (Trials)	2	2	2	2	2	2
Body Wt. (kg)	416.50 ± 23.50	413.50 ± 13.50	419.00 ± 26.00	437.00 ± 19.00	445.00 ± 16.50	441.50 ± 32.50
Milk (kg/d)	11.90 ± 0.10^{C}‡	12.53 ± 0.95^{BC}	10.90 ± 1.30^{C}	17.30 ± 0.30^{A}	15.55 ± 0.75^{A}	15.10 ± 0.00^{AB}
Dry Matter Intake (kg/d)	12.75 ± 0.65	12.50 ± 1.00	12.05 ± 1.05	14.90 ± 0.20	14.20 ± 0.20	13.15 ± 0.25
Feed Ca (%)	0.75 ± 0.04	0.79 ± 0.01	0.75 ± 0.01	0.75 ± 0.10	0.89 ± 0.01	0.73 ± 0.11
Feed P (%)	0.44 ± 0.05	0.38 ± 0.05	0.33 ± 0.04	0.45 ± 0.05	0.37 ± 0.09	0.27 ± 0.02
Feed Ca:P Ratio	1.76 ± 0.28	2.07 ± 0.29	2.31 ± 0.23	1.66 ± 0.02	2.53 ± 0.56	2.70 ± 0.57
Feed P:Ca Ratio	0.59 ± 0.10	0.49 ± 0.07	0.44 ± 0.05	0.61 ± 0.01	0.42 ± 0.10	0.39 ± 0.09
Feces Ca (g/d)	62.15 ± 3.45	73.10 ± 18.10	72.80 ± 26.20	64.90 ± 6.70	98.15 ± 9.95	84.10 ± 2.80
Urine Ca (g/d)	1.50 ± 0.20^{BC}	1.55 ± 0.15^{BC}	1.10 ± 0.00^{C}	1.60 ± 0.30^{AB}	1.75 ± 0.35^{A}	1.20 ± 0.20^{BC}
Milk Ca (g/d)	15.05 ± 0.25	15.20 ± 3.10	14.80 ± 0.80	20.75 ± 3.85	19.25 ± 0.55	13.15 ± 4.65
Ca Outgo (g/d)	78.70 ± 3.50	89.85 ± 14.85	88.70 ± 25.40	87.25 ± 3.15	119.15 ± 9.05	98.45 ± 1.65
Ca Intake (g/d)	96.20 ± 9.80	97.70 ± 7.10	90.00 ± 8.10	110.80 ± 12.80	125.80 ± 2.70	95.00 ± 11.50
Ca Balance (g/d)	17.50 ± 13.30	7.85 ± 21.95	1.30 ± 17.30	23.55 ± 15.95	6.65 ± 6.35	−3.45 ± 13.15
Ca Digested (g/d)	34.05 ± 13.25	24.60 ± 25.20	16.70 ± 17.60	45.90 ± 19.50	27.65 ± 7.25	10.90 ± 8.70
Ca Digested (%)	34.35 ± 10.25	23.45 ± 24.05	21.10 ± 22.00	39.90 ± 13.00	22.10 ± 6.30	10.50 ± 7.80
Ca Used (g/d)	32.55 ± 13.05	23.05 ± 25.05	0.50 ± 2.50	44.30 ± 19.80	25.90 ± 6.90	9.70 ± 8.50
Ca Used (%)	32.80 ± 10.20	21.90 ± 24.00	19.90 ± 21.90	38.40 ± 13.50	20.75 ± 5.95	9.30 ± 7.80
Feces P (g/d)	29.15 ± 2.15^{B}	35.55 ± 0.15^{AB}	29.85 ± 5.65^{AB}	42.35 ± 5.85^{AB}	37.20 ± 8.10^{A}	26.05 ± 9.25^{AB}
Urine P (g/d)	0.15 ± 0.15	0.25 ± 0.05	0.10 ± 0.10	0.30 ± 0.10	0.25 ± 0.15	0.15 ± 0.15
Milk P (g/d)	11.95 ± 0.15^{B}	12.40 ± 1.00^{B}	11.40 ± 1.90^{B}	18.15 ± 0.55^{A}	15.75 ± 1.05^{A}	16.10 ± 0.10^{A}
P Outgo (g/d)	41.25 ± 2.45	48.20 ± 1.20	41.35 ± 7.65	60,80 ± 5.40	53.20 ± 9.30	42.30 ± 9.50
P Intake (g/d)	55.30 ± 3.10	48.65 ± 10.05	39.65 ± 7.45	66.90 ± 6.60	51.80 ± 10.80	35.85 ± 3.25
P Balance (g/d)	14.05 ± 0.65^{A}	0.45 ± 8.85^{AB}	−1.70 ± 0.20^{AB}	6.10 ± 1.20^{AB}	−1.40 ± 1.50^{AB}	−6.45 ± 6.25^{B}
P Digested (g/d)	26.15 ± 0.95	13.10 ± 9.90	9.80 ± 1.80	24.55 ± 0.75	14.60 ± 2.70	9,80 ± 6.00
P Digested (%)	47.45 ± 0.85	23.75 ± 15.55	24.90 ± 0.20	36.95 ± 2.55	28.70 ± 1.10	29.10 ± 19.40
P Used (g/d)	26.00 ± 0.80^{A}	18.65 ± 4.05^{AB}	9.70 ± 1.70^{B}	24.25 ± 0.65^{A}	14.35 ± 2.55^{AB}	9.65 ± 6.15^{B}
P Used (%)	45.70 ± 0.20	23.30 ± 15.50	26.05 ± 1.75	36.55 ± 2.65	26.95 ± 0.05	28.80 ± 19.70
Ca:P Ratio Digested*	1.32 ± 0.55	2.77 ± 1.18	2.11 ± 2.18	1.85 ± 0.74	1.87 ± 0.15	0.91 ± 0.33
Fecal Ca/Feed Ca:P Ratio	36.62 ± 7.70	34.85 ± 3.95	32.97 ± 14.63	39.28 ± 4.64	39.88 ± 4.89	32.37 ± 5.80
Fecal Ca/Feed P:Ca Ratio	108.13 ± 11.66	158.57 ± 58.57	162.87 ± 43.38	106.24 ± 9.24	255.38 ± 82.44	231.32 ± 58.34
Fecal P/Feed Ca:P Ratio	77.22 ± 3.92	17.56 ± 2.50	13.30 ± 3.77	25.54 ± 3.15	16.21 ± 6.79	10.86 ± 5.72
Fecal P/Feed P:Ca Ratio	50.57 ± 4.54	74.60 ± 9.69^{AB}	68.01 ± 5.95^{AB}	69.60 ± 10.73^{AB}	89.88 ± 1.06^{A}	65.55 ± 9.55^{AB}
P Digested (g/d)/ Feed P:Ca Ratio	45.64 ± 5.79^{B}	24.72 ± 17.10	22.34 ± 1.83	40.28 ± 1.89	35.55 ± 1.63	30.38 ± 22.29
Lactation (day)†	113.00 ± 5.00	106.00 ± 16.00	120.00 ± 16.00	77.00 ± 16.00	77.00 ± 2.00	98.00 ± 9.00
Age (year)†	5.80 ± 2.00	58.00 ± 2.00	5.85 ± 1.95	10.60 ± 0.10	10.60 ± 0.10	10.70 ± 0.10
Gestation (mo)†	1.00 ± 1.00	0.50 ± 0.00	0.50 ± 0.50	0.50 ± 0.50	0.50 ± 0.50	1.00 ± 1.00
Grain (kg/d)	3.45 ± 0.15	3.60 ± 0.20	3.30 ± 0.20	4.80 ± 0.20	4.65 ± 0.35	4.45 ± 0.15
Vitamin D_2 (IU/d)	291,000 ± 0.00	291,000 ± 0.00	291,000 ± 0.00	145,500 ± 145,500	145,500 ± 145,500	145,500 ± 145,500

* Based on g/d digested.
† At beginning of balance trial.
‡ Means in the same row not followed by the same letter are significantly different (P<.05).

TABLE 8B.—Effects of Feeding Vitamin D_2 on Ca and P Utilization in Cows Fed Legume-Grass Silage Treated with Bacitracin.

	Treated Silage No Vitamin D_2	Treated Silage + Vitamin D_2
No. of Cows (Trials)	3	3
Body Wt. (kg)	464.00 ± 5.29	418.67 ± 5.78
Milk (kg/d)	15.83 ± 0.89	16.13 ± 0.55
Dry Matter Intake (kg/d)	14.17 ± 0.39	14.00 ± 0.64
Feed Ca (%)	0.78 ± 0.08	0.79 ± 0.07
Feed P (%)	0.36 ± 0.07	0.37 ± 0.06
Feed Ca:P Ratio	2.30 ± 0.42	2.39 ± 0.50
Feed P:Ca Ratio	0.46 ± 0.08	0.48 ± 0.09
Feces Ca (g/d)	82.53 ± 14.42	82.23 ± 5.33
Urine Ca (g/d)	1.23 ± 0.12[A]‡	1.80 ± 0.21[B]
Milk Ca (g/d)	20.37 ± 2.13	15.07 ± 3.39
Ca Outgo (g/d)	104.13 ± 12.89	
Ca Intake (g/d)	111.87 ± 14.25	109.20 ± 7.37
Ca Balance (g/d)	7.73 ± 16.62	10.10 ± 1.57
Ca Digested (g/d)	29.33 ± 18.79	26.97 ± 4.43
Ca Digested (%)	23.80 ± 15.03	24.53 ± 3.15
Ca Used (g/d)	28.10 ± 18.72	25.17 ± 4.23
Ca Used (%)	22.73 ± 15.08	22.90 ± 2.95
Feces P (g/d)	37.53 ± 5.63	32.87 ± 8.43
Urine P (g/d)	0.27 ± 0.09	0.20 ± 0.12
Milk P (g/d)	16.17 ± 0.84	17.17 ± 0.80
P Outgo (g/d)	53.97 ± 6.53	50.23 ± 8.95
P Intake (g/d)	51.20 ± 11.16	51.83 ± 9.64
P Balance (g/d)	−2.77 ± 5.77	1.60 ± 1.65
P Digested (g/d)	13.67 ± 6.27	18.97 ± 2.46
P Digested (%)	24.63 ± 7.58	38.53 ± 6.05
P Used (g/d)	13.40 ± 6.23	18.77 ± 2.44
P Used (%)	23.30 ± 7.38	38.23 ± 6.23
Ca:P Ratio Digested*	1.63 ± 0.58	1.46 ± 0.28
Fecal Ca/Feed Ca: P Ratio	35.93 ± 1.12	38.42 ± 5.93
Fecal Ca/Feed P: Ca Ratio	202.60 ± 71.08	192.70 ± 51.24
Fecal P/Feed Ca: P Ratio	18.23 ± 5.62	16.84 ± 5.85
Fecal P/Feed P: Ca Ratio	82.13 ± 4.66	67.89 ± 10.50
P Digested (g/d)/ Feed P:Ca Ratio	29.15 ± 10.63	41.66 ± 5.65
Lactation (day)†	75.00 ± 8.08	93.00 ± 8.08
Age (year)†	10.73 ± 0.03	10.53 ± 0.03
Gestation (mo)†	1.33 ± 0.33	0.00 ± 0.00
Grain (kg/d)	4.63 ± 0.20	4.63 ± 0.20
Vitamin D_2 (IU/d)	0.00 ± 0.00	291,000 ± 0.00

* Based on g/d digested.

† At beginning of balance trial.

‡ Means in the same row not followed by the same letter are significantly different ($P<.08$).

Experiments 8A and 8B

In experiments 8A and 8B, four Jersey cows were used in 12 5-day digestion balance trials. One cow was fed no vitamin D_2 and one cow was fed 291,000 I.U. of vitamin D_2/day with each of three grain concentrate mixtures in successive trials plus legume-grass silage treated with Bacitracin (5 g Zn Bacitracin/ton). Two other cows were fed vitamin D_2, 291,000 I.U./day, with untreated silage and each of the three grain concentrate mixtures during three successive digestion balance trials. Alfalfa grass hay was fed at the rate of 151 gm/45.46 kg body weight/day. The composition of the three grain concentrates, each having a different main source of energy (corn, soybran flakes, or beet pulp) are shown below.

Grain Mixtures — Experiment 8*

	1 kg	2 kg	3 kg
Ground shelled corn	386.4		
Dried beet pulp			386.4
Soybran flakes		411.8	
Soybean meal	68.2	42.7	68.2
Salt (iodized)	9.1	9.1	9.1
Bone meal	9.1	9.1	9.1

* Approximately 15% total protein.

For further details on experimental procedures, see J. Dairy Science, 1963, XLVI:1385.

Results

The results from the digestion trials based on group means with standard errors are shown in Table 8A. In Table 8B, the three vitamin D_2 fed cows were compared with the three cows fed no vitamin D_2. All six cows were fed treated silage. When all the Bacitracin-treated silage fed cows were compared with the untreated silage fed cows, differences in milk production ($P<.01$), dry matter intake ($P<.10$), urine Ca ($P<.05$), and milk P ($P<.01$) were significant.

When the three different concentrates containing corn, soybran flakes, or beet pulp as the chief source of energy (kinds of silage) were combined regardless of treatment with Bacitracin, significant differences were noted in urine Ca ($P<.05$); P intake ($P<.10$); P balance ($P<.10$); P digested, g/d ($P<.05$); P used, g/d ($P<.01$); and fecal P/P:Ca ($P<.05$). As shown in Table 8B, when the cows fed treated silage with and without vitamin D_2 were compared, only urine Ca excreted was significantly increased ($P<.08$).

Experiment 9

In experiment 9, four lactating Jersey cows were used in a 4 × 4 Latin square design involving 16 7-day digestion balance trials intended to measure the effects of feeding 0 (control), 20,000, 80,000, or 160,000 I.U. of vitamin D_2/day on calcium and phosphorus utilization. During the digestion trials, the cows were fed corn silage and chopped dehydrated alfalfa with 2.7 kg of grain mixture No. 89/day. The grain concentrate mixture consisted of ground shelled corn 227.3 kg, ground oats 90.0 kg, soybean meal 122.7 kg, bone meal 9.1 kg, and iodized salt 4.55 kg. A 7-day adjustment period was allowed between 7-day collection periods.

Results

Table 9 shows the parameters measured with group means and standard errors. Least squares analysis of variance showed no significant differences due to different levels of vitamin D_2 feeding. Lack of statistical significance may be attributed at least in part to carryover effects from the different levels of vitamin D_2 fed and the short 7-day adjustment period between trials. This suggests that the Latin square design to be suitable for measuring the type of response resulting from feeding different levels of vitamin D_2 should have much longer adjustment periods. The recent finding of Hollis *et al.* (10), showing that elevated 25-hydroxy-vitamin

TABLE 9.—Effects of Different Amounts of Vitamin D_2 on Ca and P Utilization.

	No Vitamin D_2	20,000 IU Vitamin D_2/Day	80,000 IU Vitamin D_2/Day	160,000 IU Vitamin D_2/Day
No. of Cows (Trials)	4	4	4	4
Body Wt. (kg)	383.75 ± 21.35	386.75 ± 17.45	392.75 ± 22.13	387.50 ± 19.38
Milk (kg/d)	17.65 ± 1.16	17.90 ± 2.40	17.18 ± 2.58	17.23 ± 2.22
Dry Matter Intake (kg/d)	14.93 ± 0.24‡	13.98 ± 0.23	13.45 ± 0.66	13.93 ± 1.37
Feed Ca (%)	1.29 ± 0.30	1.23 ± 0.04	1.20 ± 0.08	1.31 ± 0.05
Feed P (%)	0.29 ± 0.00	0.30 ± 0.01	0.30 ± 0.02	0.31 ± 0.02
Feed Ca:P Ratio	4.44 ± 0.08	4.04 ± 0.10	4.04 ± 0.41	4.31 ± 0.14
Feed P:Ca Ratio	0.23 ± 0.00	0.24 ± 0.01	0.26 ± 0.03	0.23 ± 0.01
Feces Ca (g/d)	86.18 ± 10.02	84.77 ± 3.95	87.08 ± 7.59	72.25 ± 3.56
Urine Ca (g/d)	0.22 ± 0.10	0.13 ± 0.08	0.24 ± 0.11	0.26 ± 0.14
Milk Ca (g/d)	20.18 ± 5.25	29.98 ± 3.00	19.98 ± 6.01	37.75 ± 10.08
Ca Outgo (g/d)	106.70 ± 5.21	110.85 ± 3.50	107.35 ± 8.45	95.27 ± 7.56
Ca Intake (g/d)	192.95 ± 5.65	180.60 ± 10.44	182.90 ± 5.30	183.47 ± 7.33
Ca Balance (g/d)	86.23 ± 4.77	69.75 ± 10.41	75.58 ± 11.48	88.15 ± 10.61
Ca Digested (g/d)	106.75 ± 6.91	95.83 ± 9.09	95.83 ± 9.40	111.20 ± 5.81
Ca Digested (%)	55.58 ± 4.39	52.70 ± 2.53	52.27 ± 4.41	60.55 ± 1.56
Ca Used (g/d)	106.40 ± 6.88	95.70 ± 9.06	95.55 ± 9.53	117.15 ± 7.59
Ca Used (%)	56.75 ± 4.15	52.68 ± 2.51	52.10 ± 4.48	60.38 ± 1.49
Feces P (g/d)	19.55 ± 2.00	13.93 ± 1.34	15.63 ± 3.68	16.48 ± 1.23
Urine P (g/d)	0.67 ± 0.39	0.34 ± 0.09	0.45 ± 0.23	0.38 ± 0.16
Milk P (g/d)	19.28 ± 2.09	19.43 ± 1.76	13.88 ± 3.74	14.08 ± 4.24
P Outgo (g/d)	39.58 ± 2.84	33.73 ± 0.60	29.98 ± 6.14	30.93 ± 2.95
P Intake (g/d)	43.50 ± 0.99	47.65 ± 4.04	45.10 ± 4.83	42.13 ± 0.59
P Balance (g/d)	3.90 ± 2.23	8.93 ± 2.70	10.15 ± 6.82	11.20 ± 3.24
P Digested (g/d)	23.98 ± 1.11	28.75 ± 1.92	24.98 ± 4.14	25.68 ± 1.21
P Digested (%)	55.33 ± 3.71	67.33 ± 2.89	66.08 ± 8.76	60.90 ± 2.81
P Used (g/d)	23.18 ± 1.30	28.38 ± 1.93	24.00 ± 3.70	25.25 ± 1.38
P Used (%)	53.53 ± 4.10	66.52 ± 2.82	59.83 ± 8.57	59.90 ± 3.20
Ca:P Ratio Digested*	4.45 ± 0.21	3.32 ± 0.16	4.03 ± 0.50	4.37 ± 0.33
Fecal Ca/Feed Ca: P Ratio	19.40 ± 2.21	20.98 ± 0.57	21.85 ± 1.15	16.75 ± 0.56
Fecal Ca/Feed P: Ca Ratio	378.63 ± 42.92	351.23 ± 23.73	356.78 ± 59.20	313.33 ± 24.86
Fecal P/Feed Ca: P Ratio	4.40 ± 0.44	3.45 ± 0.32	4.18 ± 1.20	3.82 ± 0.27
Fecal P/Feed P: Ca Ratio	85.93 ± 8.66	57.53 ± 5.84	60.10 ± 12.37	71.26 ± 6.27
P Digested (g/d)/ Feed P:Ca Ratio	105.42 ± 4.98	118.30 ± 5.66	103.59 ± 24.69	111.08 ± 7.76
Lactation (day)†	66.00 ± 7.74	66.00 ± 13.89	68.50 ± 16.64	68.50 ± 12.13
Age (year)†	3.65 ± 0.22	3.68 ± 0.24	3.68 ± 0.26	3.68 ± 0.23
Gestation (mo)†	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Grain (kg/d)	2.40 ± 0.01	2.40 ± 0.01	2.40 ± 0.01	2.40 ± 0.01
Vitamin D_2 (IU/d)	0.00 ± 0.00	20,000 ± 0.00	80,000 ± 0.00	160,000 ± 0.00

* Based on g/d digested.
† At beginning of balance trial.
‡ None of the differences among means were significant ($P<.05$).

D_3 persists for more than 56 days after injections of vitamin D_3, indicates further that switchback trials associated with vitamin D administration should be avoided unless a long adjustment period is provided.

Experiment 10

Experiment 10 was prompted by the observation that both calcium and phosphorus were utilized to a greater extent when a limited amount of grain concentrate, 0.9 to 3.6 kg/d, was added to all legume forage diets, consisting of alfalfa hay and alfalfa pellets (experiment 5A) or alfalfa-brome soilage (experiments 1A and 1B). Experiment 10 was designed to help answer the question whether the improved Ca and P utilization in experiments 1A, 1B, and 5A was due to added energy in the grain mix or to the additional phosphorus added with the grain mix. The control group, eight Jersey cows, was fed alfalfa hay free choice plus 2.27 kg of pelleted alfalfa meal. The experimental group, eight Jersey cows, was fed alfalfa hay free choice plus 4.54 kg of a pelleted mixture of equal parts alfalfa meal and corn starch. It was reasoned that the corn starch would be equivalent to adding 2.27 kg/d of "grain" with no added phosphorus.

Seven-day digestion balance trials were run on the eight Jersey cows while being fed each of the two diets with a 7-day adjustment period between trials. One-half of the cows were fed the starch containing diet at the first trial and one-half were fed the no starch diet at the first trial.

TABLE 10.—Effects on Ca and P Utilization of Adding Starch to an All-Alfalfa Diet

	Alfalfa	Alfalfa + Starch
No. of Cows (Trials)	8	8
Body Wt. (kg)	388.88 ± 8.75	392.00 ± 10.35
Milk (kg/d)	10.20 ± 0.90	11.46 ± 0.65
Dry Matter Intake (kg/d)	11.39 ± 0.51[A]‡	13.49 ± 0.65[B]
Feed Ca (%)	1.06 ± 0.20[A]	0.91 ± 0.12[B]
Feed P (%)	0.21 ± 0.01[A]	0.18 ± 0.01[B]
Feed Ca:P Ratio	5.20 ± 0.17	5.11 ± 0.19
Feed P:Ca Ratio	0.20 ± 0.01	0.20 ± 0.01
Feces Ca (g/d)	111.43 ± 13.26[A]	144.77 ± 7.08[B]
Urine Ca (g/d)	1.08 ± 0.19	0.85 ± 0.14
Milk Ca (g/d)	13.10 ± 1.99	15.58 ± 0.92
Ca Outgo (g/d)	127.34 ± 12.76[A]	160.43 ± 6.92[B]
Ca Intake (g/d)	122.36 ± 3.83	122.88 ± 4.36
Ca Balance (g/d)	−4.99 ± 11.59[A]	−37.55 ± 6.86[B]
Ca Digested (g/d)	10.88 ± 12.59[A]	−21.90 ± 7.13[B]
Ca Digested (%)	8.88 ± 10.16[A]	−18.56 ± 6.49[B]
Ca Used (g/d)	8.09 ± 11.87[A]	−21.98 ± 7.14[B]
Ca Used (%)	6.63 ± 9.59[A]	−18.60 ± 6.48[B]
Feces P (g/d)	10.99 ± 1.57[A]	15.21 ± 1.05[B]
Urine P (g/d)	0.75 ± 0.16	0.46 ± 0.09
Milk P (g/d)	9.71 ± 2.05	11.08 ± 4.02
P Outgo (g/d)	21.29 ± 2.76	26.05 ± 2.25
P Intake (g/d)	23.25 ± 0.96	24.38 ± 0.98
P Balance (g/d)	1.81 ± 2.32	1.25 ± 1.86
P Digested (g/d)	12.15 ± 1.23[A]	9.14 ± 0.76[B]
P Digested (%)	53.14 ± 5.95	37.65 ± 2.94
P Used (g/d)	11.54 ± 1.24	11.75 ± 2.50
P Used (%)	50.49 ± 6.08	49.40 ± 11.33
Ca:P Ratio Digested*	0.90 ± 1.05[A]	−2.40 ± 0.84[B]
Fecal Ca/Feed Ca:P Ratio	21.86 ± 2.89	28.58 ± 1.68
Fecal Ca/Feed P:Ca Ratio	569.30 ± 65.82	721.14 ± 44.63
Fecal P/Feed Ca:P Ratio	2.17 ± 0.33	3.04 ± 0.31
Fecal P/Feed P:Ca Ratio	55.72 ± 7.71[A]	75.08 ± 4.21[B]
P Digested (g/d)/ Feed P:Ca Ratio	63.24 ± 7.54	45.50 ± 4.01
Lactation (day)†	159.50 ± 18.33	159.25 ± 20.52
Age (year)†	3.28 ± 0.25	3.28 ± 0.26
Gestation (mo)†	0.75 ± 0.62	0.75 ± 0.62
Grain (kg/d)	0.00 ± 0.00	2.27 ± 0.00 (starch)
Vitamin D_2 (IU/d)	0.00 ± 0.00	0.00 ± 0.00

* Based on g/d digested.
† At beginning of balance trial.
‡ Means in the same row not followed by the same letter are significantly different ($p<.05$).

Results

The results and the parameters measured are shown as group means with standard errors in Table 10. Least squares analysis of variance revealed significantly ($P<.05$) lower values in the cows fed added starch for the following parameters: feed Ca, %; feed P, %; Ca balance; Ca digested, g/d; Ca digested, %; Ca used, g/d; Ca used, %; P digested, g/d; and Ca:P ratio digested.

In the starch-fed cows, the following parameters had significantly higher values: dry matter intake ($P<.05$); fecal Ca ($P<.05$); Ca outgo, g/d ($P<.05$); fecal P ($P<.05$); fecal P/feed P:Ca ratio ($P<.05$); fecal Ca/feed Ca:P ratio ($P<.10$); fecal Ca/feed P:Ca ratio ($P<.10$); and fecal P/feed Ca:P ratio ($P<.10$). In view of the unexpected lowering of both calcium and phosphorus utilization in the starch-fed cows and the extremely low digestibility of Ca and low P intake and negative balance in several cows, the experiment was repeated in experiment 11 with diammonium phosphate added to provide approximately 0.4% P in the total ration compared to approximately 0.2% P in experiment 10.

Experiment 11

In experiment 11, half of the eight Jersey cows were fed alfalfa hay free choice plus 5 lb of a pelleted mixture of alfalfa meal (reground pellets) 93%, diammonium phosphate (Duofos) 6%, and iodized salt 1%. The other half were fed alfalfa hay free choice plus

TABLE 11.—Effects on Ca and P Utilization of Adding Starch and Diammonium Phosphate to an All-Alfalfa Diet.

	Alfalfa	Alfalfa + Starch
No of Cows (Trials)	8	8
Body Wt. (kg)	428.50 ± 16.57	428.50 ± 16.57
Milk (kg/d)	8.80 ± 0.90	8.54 ± 0.98
Dry Matter Intake (kg/d)	12.28 ± 0.51	12.79 ± 0.57
Feed Ca (%)	1.94 ± 0.06[A]‡	1.61 ± 0.05[B]
Feed P (%)	0.49 ± 0.02[A]	0.42 ± 0.01[B]
Feed Ca:P Ratio	4.03 ± 0.21	3.90 ± 0.18
Feed P:Ca Ratio	0.26 ± 0.01	0.26 ± 0.01
Feces Ca (g/d)	176.63 ± 9.03	171.70 ± 5.69
Urine Ca (g/d)	1.25 ± 0.05[A]	1.05 ± 0.06[B]
Milk Ca (g/d)	13.22 ± 1.59	13.31 ± 1.75
Ca Outgo (g/d)	190.92 ± 10.34	185.95 ± 6.67
Ca Intake (g/d)	238.92 ± 13.95	207.75 ± 10.57
Ca Balance (g/d)	48.00 ± 9.75	21.83 ± 9.05
Ca Digested (g/d)	57.79 ± 12.01	36.08 ± 9.51
Ca Digested (%)	22.80 ± 4.15	16.33 ± 4.16
Ca Used (g/d)	62.43 ± 10.52	35.13 ± 9.54
Ca Used (%)	25.36 ± 3.58	15.81 ± 4.19
Feces P (g/d)	45.63 ± 1.52	42.36 ± 1.52
Urine P (g/d)	0.07 ± 0.01	0.06 ± 0.00
Milk P (g/d)	6.39 ± 0.63	6.66 ± 0.87
P Outgo (g/d)	52.13 ± 1.52	49.06 ± 1.66
P Intake (g/d)	59.30 ± 0.81[A]	52.50 ± 1.42[B]
P Balance (g/d)	7.05 ± 1.72	3.43 ± 1.19
P Digested (g/d)	13.65 ± 1.90	9.98 ± 1.75
P Digested (%)	22.85 ± 2.99	18.78 ± 3.07
P Used (g/d)	13.31 ± 1.87	9.98 ± 1.87
P Used (%)	22.30 ± 2.92	18.66 ± 3.28
Ca:P Ratio Digested*	4.77 ± 1.41	2.98 ± 1.68
Fecal Ca/Feed Ca:P Ratio	44.17 ± 2.08	44.60 ± 2.39
Fecal Ca/Feed P:Ca Ratio	713.04 ± 61.85	674.08 ± 42.23
Fecal P/Feed Ca:P Ratio	11.57 ± 0.81	11.02 ± 0.69
Fecal P/Feed P:Ca Ratio	182.14 ± 11.14	165.95 ± 9.72
P Digested (g/d)/Feed P:Ca Ratio	55.18 ± 8.74	39.56 ± 6.69
Lactation (day)†	242.50 ± 21.31	241.25 ± 19.57
Age (year)†	5.56 ± 0.56	5.56 ± 0.56
Gestation (mo)†	2.25 ± 0.59	2.25 ± 0.59
Grain (kg/d)	0.00 ± 0.00	2.27 ± 0.00 (starch)
Vitamin D_2 (IU/d)	0.00 ± 0.00	0.00 ± 0.00

* Based on g/d digested.

† At beginning of balance trial.

‡ Means in the same row not followed by the same letter are significantly different ($P<.05$).

10 lb of a pelleted mixture of alfalfa meal (reground pellets) 46.5%, diammonium phosphate (Duofos) 3%, iodized salt 1.5%, and corn starch 50%. As in experiment 10, half of the cows were fed the no starch diet during the first trial and the other half were fed the starch diet during the first trial. There was a 9-day adjustment period between the two 7-day collection periods.

Results

The results are shown in Table 11 as group means with standard errors for the parameters measured. Least squares analysis of variance showed significant decreases due to added starch in the feed for the following parameters: feed Ca, % ($P<.01$); feed P, % ($P<.01$); urine Ca ($P<.05$); Ca intake ($P<.10$); Ca balance ($P<.10$); Ca used, g/d ($P<.10$); P intake ($P<.01$); and P used, g/d ($P<.10$).

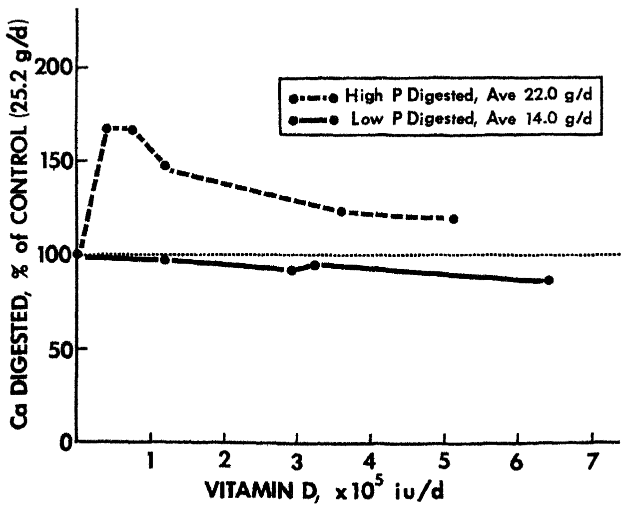

FIG. 2.—Ca digested, g/d, as affected by P digested and dosage of vitamin D_2. Ca digested is expressed as percent of the average amount digested by the cows fed no vitamin D_2 (av. 25.2 g/d).

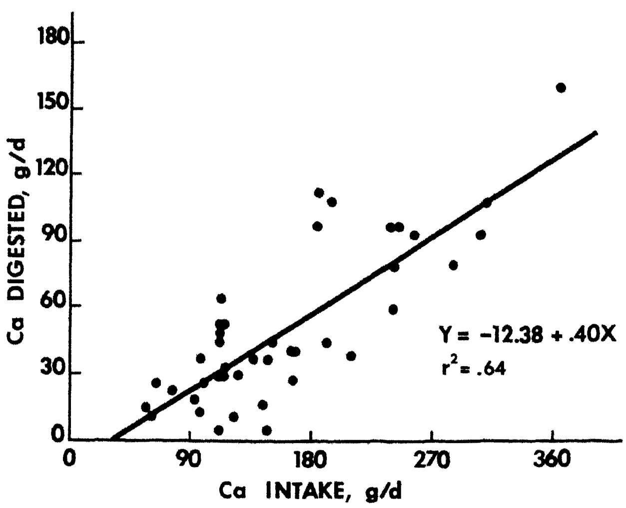

FIG. 3.—Relationship between Ca digested and Ca intake.

Although no ready explanation can be made for the decreases in calcium and phosphorus utilization in both experiments 10 and 11, certainly there were no increases due to starch feeding. This result suggests that the increased Ca and P utilization elicited by adding grain concentrate to the all-forage diets in experiments 1A, 1B, and 5A was not associated with the added energy (starch) but more likely was the result of added P, making the phosphorus intake more favorable to better utilization of both Ca and P. This was later confirmed by Bargeloh *et al.* (J. Dairy Sci., 55:707, 1972), who showed there was no difference in Ca and P digested from adding grain where the P content of the diet was equalized.

DISCUSSION

Phosphorus Digestion and Vitamin D_2 Feeding Response

In order to examine the possible effects of level of phosphorus digestion on calcium digestion in response to different levels of vitamin D_2 feeding, the combined Jersey data from experiments 1A, 2, 5B, and 8B (low P digested groups, av. = 14 g/d) were compared with the Jersey data from experiments 3 and 7 (high P digested groups, av. = 22 g/d). In Figure 2, calcium digested by these two groups, expressed as percent of the amount digested by the cows fed no vitamin D_2 (av. 25.2 g/d), is plotted against level of vitamin D_2 fed. The unpaired t test showed a significant difference in Ca digested between the two groups.

As level of vitamin D_2 increased, the low P digested group declined gradually in calcium digested, g/d, showing no response to vitamin D_2 feeding. In the group where P digested was higher (av. 22 g/d), there was a maximum increase in Ca digested (g/d) from feeding as little as 40,000 I.U. of vitamin D_2/day. This response declined gradually at daily doses of vitamin D_2 greater than 80,000 I.U/d. It was concluded that no response in calcium digestion to feeding vitamin D_2 can be expected if P digestion is below about 14 g/d. At higher levels of P digestion (av. 22 g/d), maximum Ca digestion can be attained by feeding as little as 40,000 I.U. of supplemental vitamin D_2/d.

The overall insignificant increases in calcium digested elicited by feeding vitamin D_2 in these experiments was likely due in part to the generally high level of calcium intake. All were above 100 mg/day/kg BW, below which, according to Braithwaite (3), Ca absorption in wethers is dependent on active Ca transport in the intestine. The active Ca transport is dependent on vitamin D and is related to body needs. Above 100 mg/day/kg BW, Ca absorption increased in direct relation to Ca intake by diffusion (3) and is not dependent on vitamin D and active Ca transport.

Figure 3 shows the relation of Ca intake to Ca digested in these experiments. At 90 g/d calcium intake based on 397 kg body weight (the average of the Jersey cow groups in these experiments), the intake of calcium was equivalent to 229 mg/kg per day. Over the range of Ca intake in these 11 experiments, the correlation between Ca intake and Ca digested was high (r = 0.80) (Fig. 3). That Ca digestion did not level off at the higher Ca intakes, up to 360 g/d (920 mg/d/kg BW), indicated, according to Braithwaite (2), that bone mineralization was not saturated in these lactating cows. Heaney *et al.* (8) working with humans also found that calcium was absorbed in relation to intake when Ca intake was high, whereas at Ca intake levels below 0.8 g/d (approximately 14 mg/kg/d) there was a curvilinear relationship with absorption, suggesting that calcium absorption was being regulated according to need (3, 12).

Effects of Grain Concentrate Feeding on Calcium Digested

In the data from experiments 1A, 1B, and 5A where comparisons were made between no grain concentrate feeding and adding grain concentrate to alfalfa or legume grass forage, an increase in calcium and phosphorus utilization was found when grain concentrate was added (Table 12). Based on the results in experiments 10 and 11, which showed that adding corn starch to ground alfalfa pellets plus alfalfa hay reduced Ca and P utilization (Tables 10 and 11), it was reasoned that the higher P intake provided by the grain concentrate may have been responsible for the increased Ca and P utilization when grain concentrate was fed (Table 12). Certainly the increased Ca and P utilization was not due to the added starch in the grain concentrate (Tables 10 and 11). Indeed, when the means for Ca digested (g/d) in all 11 experiments were plotted against P digested (g/d) (Fig. 4), a highly significant correlation (r = 0.54) between P digested (g/d) and Ca digested (g/d) was found.

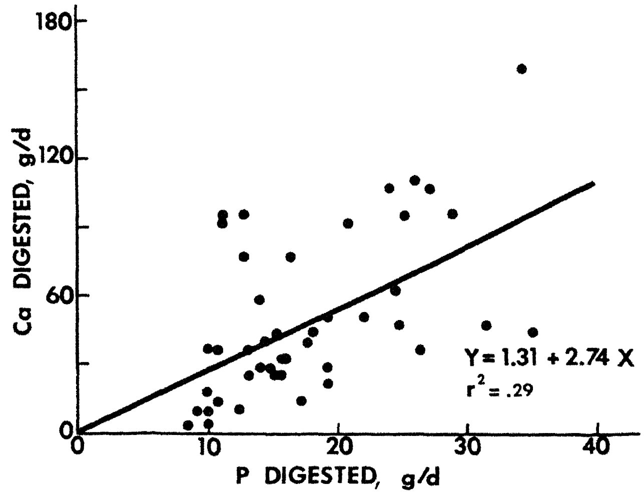

FIG. 4.—Relationship between Ca digested and P digested.

Figure 5 shows a significant correlation between Ca digested % and P digested %, r = 0.64. Phosphorus digested was also highly correlated with P intake (r = 0.70) (Fig. 6). This suggests that the higher P intake in the grain-fed groups (Table 12) resulted in increased P digested along with increased Ca digested. Braithwaite (2) has also shown a direct relationship between P intake and P absorbed. Homeostasis was regulated largely by changes in urinary P.

Feed Ca:P Ratio and Utilization of Ca and P

Considerable attention has been paid to the relationship between feed Ca:P ratio and the utilization of Ca

TABLE 12.—Effects of Adding Grain Concentrate to Alfalfa or Legume Grass Forage on Calcium and Phosphorus Utilization.

	No Grain Fed§	Grain Fed§
No. of Experiments	5	5
No. of Trials	16	9
Body Wt. (kg)	382 ± 8.6^{B}‡	427 ± 5.9^{A*}
Milk (kg/d)	10.1 ± 0.9^{B}	12.8 ± 1.5^{A*}
Grain Fed (kg/d)	0.0	2.1
P Intake (g/d)‡‡	39.1 ± 3.3^{B}	49.1 ± 3.1^{A*}
P Balance (g/d)	2.5 ± 1.9^{B}	7.8 ± 2.8^{A}†
P Digested (g/d)	13.2 ± 2.2^{B}	22.4 ± 3.5^{A**}
P Digested (%)	32.6 ± 4.1^{B}	44.8 ± 4.5^{A**}
Ca Intake (g/d)	170.0 ± 53.2	189.0 ± 61.2
Ca Balance (g/d)	17.5 ± 18.9	36.8 ± 27.2
Ca Digested (g/d)	38.9 ± 18.8^{B}	63.9 ± 29.4^{A}†
Ca Digested (%)	20.4 ± 5.0^{B}	31.3 ± 5.9^{A**}
Ca Digested/P Digested (g/d)	2.95 ± 0.09	2.85 ± 0.08
Av. Vitamin D_2 Fed (IU/d)	160,000	320,000

‡ Experiment means in the same row not followed by the same letter are different (*=P<.05, **=P<.01, †=P<.10).

§ Experiments included were 1A (2), 1B (2), and 5A.

‡‡ Cows in No Grain Fed group were 24.1% over NRC requirement for P. Cows in Grain Fed group were 30.0% over NRC requirement for P.

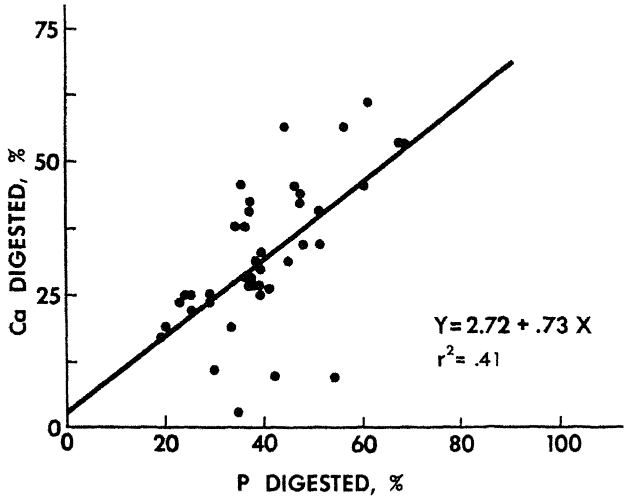

FIG. 5.—Relationship between percent Ca digested and percent P digested.

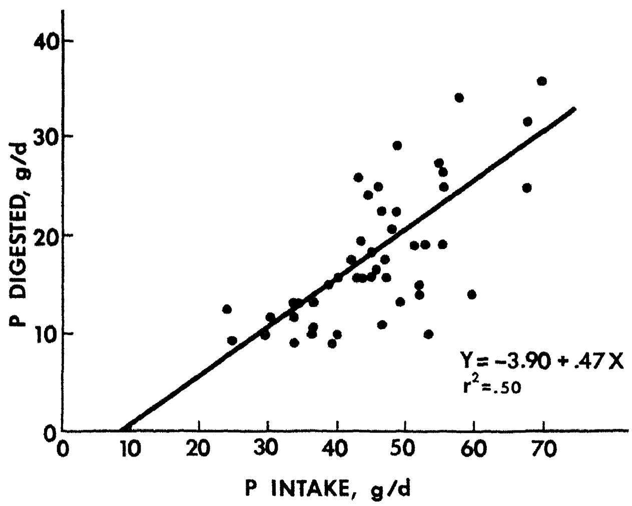

FIG. 6.—Relationship between P digested and P intake.

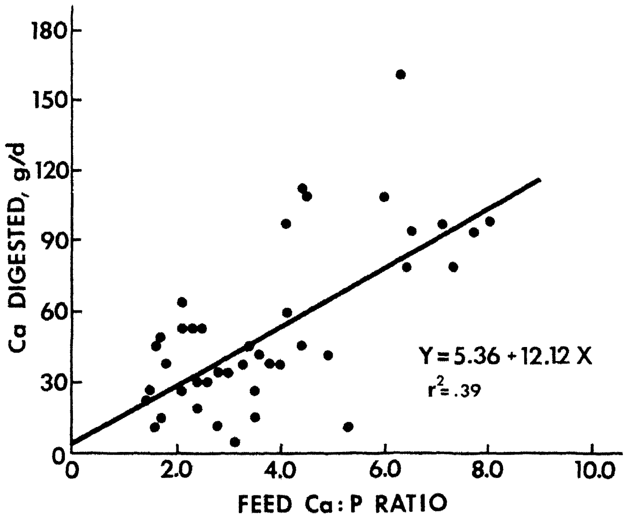

FIG. 7.—Relationship between Ca digested and feed Ca:P ratio.

and P. Young *et al.* (13) concluded that while the availability of P was lowered by a diet deficient in P with a wide Ca:P ratio, there was no effect of Ca:P ratio on P absorption when P intake was adequate. Low Ca absorption resulted from feeding a diet low in P and was increased when P intake was raised (13). It was pointed out that ruminants tolerate a wider range in dietary Ca:P ratio than non-ruminant animals, perhaps because of different sources of dietary phosphorus and better utilization of phytin phosphorus.

In the 11 experiments, the relationship of feed Ca:P ratio to Ca digested (g/d) is shown in Figure 7. The correlation coefficient was r = 0.63. Figure 8 shows the relationship between feed Ca:P ratio and the Ca:P ratio of the digested Ca and P with a correlation coefficient of r = 0.76. Thus, there was a wider Ca:P ratio digested as the Ca:P ratio in the feed widened. Figures 3 and 6 show that Ca digested (g/d) was significantly correlated with increases in both Ca and P intake.

Young *et al.* (13) showed that Ca absorption increased as Ca intake increased when P intake was adequate, even at a wide Ca:P ratio, 9.9:1. It was also demonstrated by Abdel-Hafeez *et al.* (1) that increasing P intake from low to high enhanced the absorption of calcium.

Huffman *et al.* (11) conducted digestion balance trials with Holstein cows and concluded that total intake of calcium or phosphorus has a greater significance in their utilization than has the feed Ca:P ratio. Data in these 11 experiments bear out this conclusion based on the following correlation coefficients (r) using Ca digested rather than Ca used.

	Ca or P Intake g/d	Feed Ca:P Ratio
Ca digested, g/d	0.80	0.63
P digested, g/d	0.70	—0.14

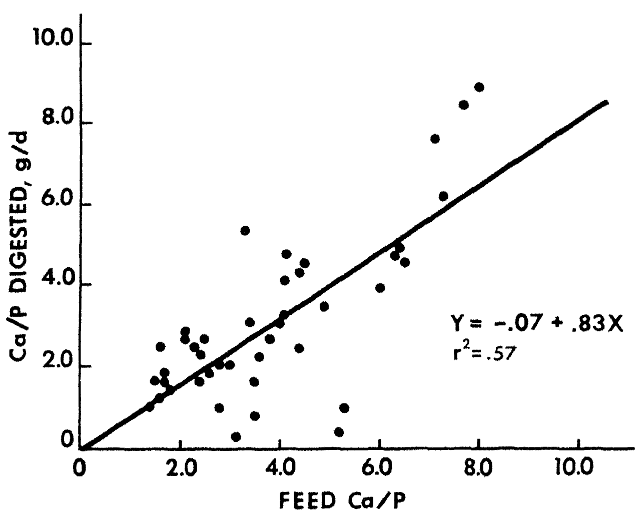

FIG. 8.—Relationship between Ca:P ratio of the digested Ca and P and feed Ca:P ratio.

This does not mean that feed Ca:P ratios cannot be used to help explain changes in metabolism of Ca and P as discussed below. The following correlations were found not to be significant: P digested, g/d, vs. feed Ca:P ratio; P digested, g/d, vs. Ca intake, g/d; P digested, g/d, vs. feed P:Ca ratio; Ca digested, g/d, vs. P intake, g/d; and Ca digested, g/d, vs. feed P:Ca ratio.

Relation of P Balance to Ca Digested

While the correlation was not high ($r = 0.50$), there was a significant positive relationship between phosphorus balance and calcium digested (g/d) (Fig. 9). Figure 10 showed a significant correlation between P balance and Ca digested %, $r = 0.59$. These probably reflect the positive relationship between P intake and Ca digested shown in Figure 6.

Relationship Between Ca and P Absorption and Ca and P Intake

Holemans and Meyer (9) working with human subjects have discovered a quantitative association between Ca and P absorption and their dependence on Ca and P intake. They showed a highly significant correlation between fecal P and fecal Ca ÷ Ca:P ratio in the diet, $r = 0.88$. The regression was calculated as follows:

Y (fecal P) = 1.48 + 0.515 × (fecal Ca ÷ Ca:P ratio in the diet).

For the sake of simplicity, this formula was changed to:

$$\text{Fecal P} = 0.5 \; \frac{\text{fecal Ca}}{\text{Ca:P ratio in diet}}$$

This formula also can be written:

$$\text{Fecal P} = 0.5 \; \frac{\text{fecal Ca}}{\text{Ca intake}} \times \text{P intake.}$$

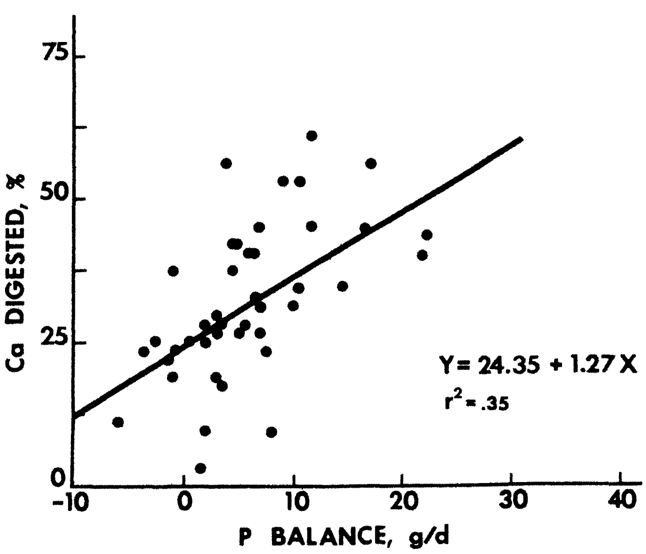

FIG. 10.—Relationship between percent Ca digested and P balance.

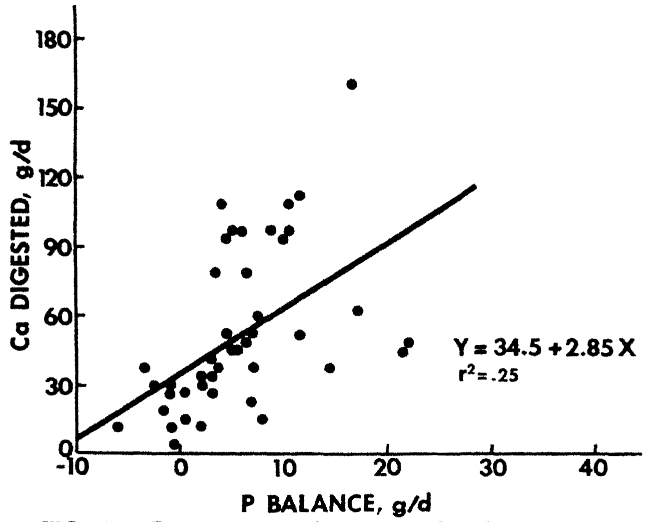

FIG. 9.—Relationship between Ca digested and P balance.

The correlation between fecal P and fecal Ca ÷ Ca:P ratio in the feed in these cow experiments was high, $r = 0.81$. The regression was calculated as follows:

Y (fecal P) = 0.09 + 0.88 × (fecal Ca ÷ Ca:P ratio in the feed) (Fig. 11).

A highly significant correlation was also found between fecal Ca and fecal P ÷ P:Ca in the feed, $r = 0.91$. The regression was calculated as follows:

Y (fecal Ca) = 9.97 + 1.05 × (fecal P ÷ P:Ca ratio in the feed) (Fig. 12).

In ration formulations, the primary concern is with Ca and P absorbed. Thus Figure 13 shows the correlation between Ca digested, g/d, and P digested, g/d, ÷ P:Ca ratio in the feed. The correlation was highly significant, $r = 0.89$. The regression was calculated as follows:

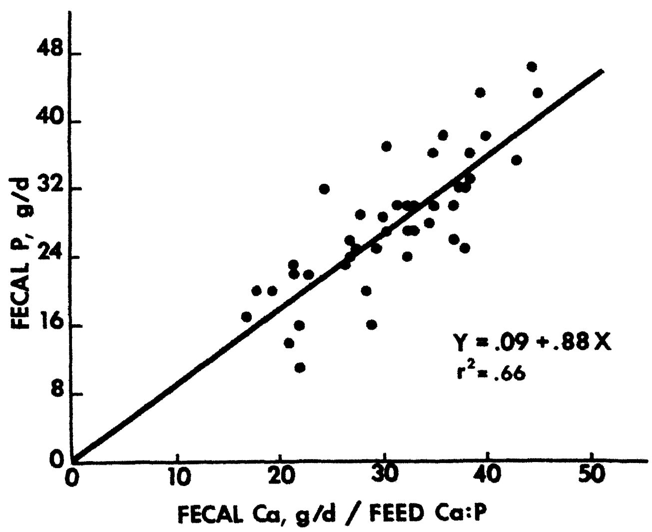

FIG. 11.—Relationship between fecal P and fecal Ca/feed Ca:P ratio.

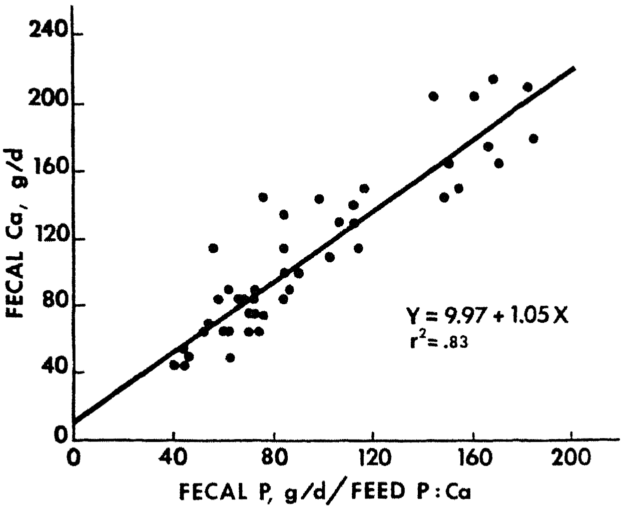

FIG. 12.—Relationship between fecal Ca to fecal P/feed Ca:P ratio.

Y (Ca digested, g/d) = 0.30 + 0.79 × (P digested, g/d ÷ P:Ca ratio in the feed) (Fig. 13).

This formula can also be expressed:

$$\text{Ca digested, g/d} = 0.30 + \frac{0.79 \times \text{P digested, g/d}}{\text{P intake, g/d} \div \text{Ca intake, g/d}}$$

Simplified, this formula reads:

$$\text{Ca digested, g/d} = 0.8 \times \frac{\text{P digested, g/d}}{\text{P intake, g/d}} \times \text{Ca intake, g/d}$$

where:

$$\frac{\text{P digested, g/d}}{\text{P intake, g/d}} = \text{decimal proportion or ratio of P digested to P intake.}$$

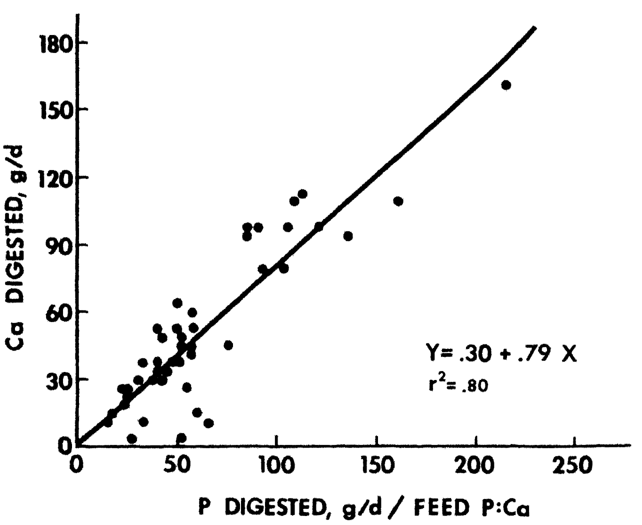

FIG. 13.—Relationship between Ca digested and P digested/feed P:Ca ratio.

This relationship can also be expressed:

Ca digested, g/d = 0.8 P digested, g/d × Ca:P ratio in the feed.

Thus either actual or table values can be used for P digested, g/d; P intake, g/d; and Ca intake, g/d (or Ca:P ratio in the feed) to calculate Ca digested, g/d.

By using either actual or table values for Ca digested, g/d; P intake, g/d; and Ca intake, g/d; P digested, g/d, can be calculated from the above formula as follows:

$$\text{P digested, g/d} = \frac{\text{Ca digested, g/d}}{0.8} \times \frac{\text{P intake, g/d}}{\text{Ca intake, g/d}}$$

P digested, g/d = 1.25 × P intake, g/d × decimal proportion of Ca intake digested,

or

P digested = 1.25 × Ca digested × P:Ca ratio in the feed.

Referring back to Figure 8 and the regression formula for Ca:P ratio digested vs. Ca:P ratio in the feed, it is seen that:

Ca:P ratio digested = 0.07 + (0.83 Ca:P ratio in the feed).

This formula can be simplified as follows:

Ca:P ratio digested = 0.8 × Ca:P ratio in the feed.

This formula can be written:

$$\frac{\text{Ca digested, g/d}}{\text{P digested, g/d}} = 0.8\ \frac{\text{Ca intake, g/d}}{\text{P intake, g/d}}$$

Therefore:

$$\text{Ca digested, g/d} = 0.8 \times \text{P digested, g/d} \times \frac{\text{Ca intake, g/d}}{\text{P intake, g/d}}$$

or

Ca digested, g/d = 0.8 × decimal proportion of P intake digested × Ca intake, g/d

or

Ca digested = 0.8 × P digested, g/d × Ca:P ratio in the feed.

Thus, the regression formulas for both Figures 8 and 13 can be used in calculating either Ca or P digested if Ca intake and P intake are known or can be estimated from table values. However, the formula in Figure 13 (r^2 = 0.80) is more precise than the formula in Figure 8 (r^2 = 0.57).

Factors Affecting Ca Digestion

In order to determine the factors that markedly affected the absorption of Ca, a stepwise multiple regression was run using the data from all 11 experiments where the independent variable was Ca digested, g/d, and the dependent variables were feed Ca:P ratio; Ca intake, g/d; Ca digested, g/d; P intake, g/d; P digested, g/d; fed or not fed vitamin D_2; day of lactation; milk, kg/d; and milk Ca, kg/d.

Least squares analysis of variance showed that four of the nine independent variables were significant: Ca intake, P digested, fed or not fed vitamin D_2, and day of lactation. The following formula represents the multiple regression:

Ca digested, g/d = —28.32 + 0.38 Ca intake, g/d + 1.71 P digested, g/d + 9.33 vitamin D_2 — 0.12 day of lactation.

The R^2 value of 0.84 indicates that 84% of the variation was accounted for by these four factors.

Conclusions based on this analysis were: 1) an average of 38% of the Ca in the feed was digested in these 11 experiments; 2) 1.71 grams of Ca were digested for every gram of P digested, thus the Ca:P ratio of the digested Ca and P was 1.71:1 (Ca digested was previously shown to be markedly influenced by both P intake, Figure 3, and Ca intake, Figure 2); 3) an average of 9.33 more grams of Ca were digested daily in cows fed vitamin D_2 than in cows fed no vitamin D_2 (Figure 2 showed that response in Ca digested, g/d, due to vitamin D_2 feeding reached maximum at 40,000 I.U./day and declined with increasing dosage above 80,000 I.U./day); and 4) as lactation advanced, 0.12 gm less Ca was digested each day. This further confirms the finding of Visek *et al.* (12), working with lactating goats, and Braithwaite (3), working with sheep, that Ca is absorbed in accordance with need.

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